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FISH AND WILDLIFE AS RELATED TO WATER QUALITY OF THE LAKE SUPERIOR BASIN

Fish and Wildlife Service
Washington, D. C.

June 1970

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UNITED STATES DEPARTMENT OF THE INTERIOR

Fish and Wildlife Service

FISH AND WILDLIFE AS RELATED TO WATER QUALITY
OF THE
LAKE SUPERIOR BASIN

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A Special Report on
Fish and Wildlife Resources

June 1970

174

REPORT OF THE REGIONAL DIRECTORS

Bureau of Commercial Fisheries

Bureau of Sport Fisheries and Wildlife

UNITED STATES
DEPARTMENT OF THE INTERIOR
U. S. Fish and Wildlife Service

Mr. Francis T. Mayo, Regional Director
Federal Water Quality Administration
U. S. Department of the Interior
33 East Congress Parkway, Room 410
Chicago, Illinois 60605

Dear Mr. Mayo:

This is a report on the effects of water quality upon the fish and wildlife resources of the Lake Superior Basin. It has been prepared under the authority and in accordance with the provisions of the Fish and Wildlife Coordination Act (48 Stat. 401, as amended; 16 U.S.C. 661 et seq.). This is the last of our fish and wildlife reports in the series covered by your Great Lakes-Illinois River Basin Comprehensive Study.

This letter briefly summarizes the findings of the Bureau of Sport Fisheries and Wildlife and the Bureau of Commercial Fisheries regarding the status of fish and wildlife resources in the basin and their relationships to present and future water quality. It is supported in detail by information included in the attached substantiating report. The study gives principal emphasis to U. S. waters of the basin, but the international aspects of the problem are recognized.

Lake Superior is the largest and deepest of the Great Lakes. It measures 350 miles long by 160 miles wide, with a maximum depth of 1,333 feet. The western two-thirds of the lake has a relatively smooth basin, while the eastern third has a ridge and trough topography. Only 17.5 percent is shallower than 100 feet, while 51 percent is deeper than 420 feet. The only important stretches of shallow water lie in the Apostle Island Region, Whitefish Bay and the Bay Region of the North. The principal islands are Isle Royale, Michipicoten and the Apostle Island group.

The Lake Superior Basin lies almost wholly on igneous and metamorphic rocks of the Pre-Cambrian era of the Canadian shield. This drainage is relatively infertile, contributing to low productivity and the oligotrophic character of Lake Superior. It is unique among the Great Lakes in that it is nearly surrounded by high lands with generally rocky shores.

Fishery Resources

Lake Superior has been long renowned for its high quality sport fishery. Sport fishing, especially in the bays and shoal areas, including the area around the Apostle Islands, Keweenaw Bay, and numerous tributaries, has provided high value recreational opportunities for over 100 years. Lake trout, walleye, northern pike, and whitefish received most of the early attention. Fishing for these species was especially productive until about 1950. By that time, the inroads of the sea lamprey had resulted in severe setbacks to both sport and commercial fishing.

The lamprey control programs of recent years, augmented by fish stocking programs, have reversed the downward trends and fishing is gradually coming back. Introductions of such species as rainbow trout, brown trout, smelt and coho salmon have also added considerable variety to sport fishing. Charter boats are once more becoming active and are providing considerable stimulus to tourism and the area economy. In recent years smelt dipping has assumed carnival-like proportions. Each spring thousands of fishermen congregate along numerous tributaries to dip these silvery little fish during the spawning runs.

In 1960, approximately 225,000 fishing licenses were sold in the U. S. portion of the basin. Numerous additional fishermen purchased their licenses elsewhere, but fished in Lake Superior or its tributaries. An estimated 300,000 fishermen fished in U. S. waters of Lake Superior Basin in 1965, with an estimated 5,520,000 fisherman days expended there. By 1980, this figure is expected to increase to 8,300,000. By the year 2020, fishing pressure is estimated at 20,000,000 fisherman days.

Historically, Lake Superior has been dominated by salmonid fishes. The three principal species in the commercial catch have been lake trout, whitefish and lake herring. The peak period for commercial production was during the 1940's, when the average yearly catch from the lake (U. S. and Canada) was over 21 million pounds.

Though there have been some changes in the fishery stocks throughout the period of record, the major changes have occurred during the last two decades. In the 1950's, heavy commercial fishing pressures on the lamprey-reduced stocks accelerated the inevitable collapse of the lake trout. The lake herring population began showing evidence of decline in the mid-1950's and the decline has continued since then. Competition from smelt, overfishing, and other factors have been blamed. Although herring were once widely dispersed throughout the Great Lakes, they represented the first major fishery in Lake Erie to collapse (in the 1920's). Environmental changes are considered at least partially responsible. Lake Superior's commercial fishery has undergone a steady decline in both total production and value since the early 1950's, primarily due to the decline of the three high value species. Annual production averaged only 14 million pounds during the 1960's.

Improvement of this presently unfavorable situation is the chief challenge facing fishery management in the Lake Superior Basin. Solutions will require close coordination of effort between the sport and commercial fisheries, leading to balanced utilization of the total fishery resource. Re-establishment of a balanced predator-prey relationship in Lake Superior is considered essential to achieve a stable and productive resource base. This will require intensification and expansion of lamprey control and continued selective stockings of predator species. Careful monitoring of the fishery base will be necessary as these activities proceed, in order to determine the nature of the changes that occur and to indicate possible necessary adjustments in management procedures.

Wildlife Resources

The Lake Superior Basin supports both a variety and an abundance of wildlife. Deer provide hunting for thousands of hunters and black bear are locally common. Other game species include ruffed grouse, spruce grouse, woodcock, snowshoe hares, and squirrels. Another species of special or unusual interest is the moose. It is locally common in Minnesota, Wisconsin, and Canadian portions of the basin and on Isle Royale. Protected for many years throughout much of the basin, this magnificent animal is now being considered for restoration to Minnesota's big game list. Several other species are either rare or uncommon. They have persisted in more primitive portions of the basin, where the inroads of civilization have not forced their disappearance. The timber wolf, a rare and endangered species in many parts of its range, still ranges in Minnesota and Canadian portions of the basin and on Isle Royale. Marten are still resident in the basin and fisher have been re-introduced. Both are interesting additions to the basin fauna.

In terms of total numbers, there are more game animals in parts of the basin today than were reported in the virgin forests of earlier periods. Recently, however, such problems as disappearing habitat, from forest succession or other causes, together with insecticides, and pollution are having a negative effect upon some forms of wildlife in the basin. Conservationists are making special efforts to protect the area's natural resources and to minimize the impact of man's activities in this relatively unspoiled area.

Waterfowl use consists primarily of diving ducks. Scaups, ringnecks, goldeneyes and mergansers are abundant. Large concentrations of diving ducks raft up in Lake Superior and the nearby lakes during migration periods. Several species of geese migrate through the basin and goose shooting is locally good. Loons are common in much of the basin and add considerably to the wilderness appeal of this area.

Approximately 200,000 hunting licenses were sold in the U. S. portion of Lake Superior Basin in 1965. These hunters spent an estimated 2,740,000 hunter days in the basin. This activity is expected to increase to 4,000,000 hunter days by 1980 and to 5,500,000 by the year 2020.

Fish, Wildlife and Water Quality Relationships

A large share of the economic and recreational values of the Lake Superior Basin depends directly upon the lake, its bays and inshore waters, and tributary streams. Fish and wildlife are vitally dependent upon high quality water which meets the various biological requirements for feeding, growth, reproduction, and survival.

Fish and aquatic life play a unique role with respect to water quality problems, particularly in such large and complex ecosystems as the Great Lakes. Long before water quality changes are detectable in gross forms and before they result in closed beaches and unacceptable domestic water supplies, various biologic interactions in the lake can reveal the significance and rate of these changes. They can provide early warning of the need for remedial action. This is particularly true in Lake Superior, where a huge volume of exceptionally high quality water has supported an aquatic life complex dominated by high quality fish with exacting environmental requirements. This complex is characterized by lake trout, whitefish, and lake herring. It has deteriorated in some areas of the Great Lakes ecosystem, probably due to a combination of events, including environmental changes.

The open waters of Lake Superior are still exceptionally pure. The attached, detailed report substantiates the high quality of these waters, which presently surpass the state water quality standards established incident to the Water Quality Act of 1965. Dissolved oxygen is normally near saturation at all depths and at times reaches supersaturated conditions. Concentrations of dissolved solids are low, with very little change occurring during the period of record (1880 to the present).

Based on the few parameters for which reliable data are available over a long period of time, changes have been of a minor order. The areas of concern about which the most is known, however, are not necessarily the most critical ones for fish and aquatic life. For example, pesticides exemplify a much different problem than dissolved solids. Recent studies indicate that pesticide concentrations in Lake Superior fish are the lowest of any in the Great Lakes. However, these concentrations are sufficient to be a cause for concern, since they have accumulated over a relatively short time. Projected concentrations suggest possible serious problems. Salmonids and some other high quality fishes have a special capacity to accumulate pesticidal substances in their bodies, particularly as the fish develop into the larger size classes. This has disturbing ramifications for the future management of both commercial and sport fishing in Lake Superior.

With its relatively high quality waters, the discharge from Lake Superior into the rest of the Great Lakes system exerts a major stabilizing effect in maintaining water quality levels in the lower lakes, particularly in Lake Huron. If pollution inputs now entering Lake Erie are eventually abated, Lake Superior will be the major source for the flushing flows that may rehabilitate that lake and its fisheries.

In contrast to the open lake, the inshore waters and stream-mouth zone are more critical from the standpoint of indicating actual or incipient environmental change. Apart from its indicator role, this zone is of

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special importance in the life histories of several valuable species. These include anadromous fishes such as smelt, rainbow, brown and brook trout, coho and chinook salmon and inshore spawners such as lake herring.

The inshore waters of Lake Superior as a whole do not as yet exhibit widespread indications of water quality deterioration. There are important exceptions, however. These areas and causative factors include the taconite tailings at Silver Bay, Minnesota; paper mill wastes at Nipigon Bay, Ontario; pulp and paper mill wastes at Thunder Bay, Ontario; observable industrial degradation from various sources in the Duluth-Superior area; municipal wastes from Duluth and Superior and a comparatively few other population concentration points in the basin, and from scattered logging and sawmilling operations.

From the standpoint of fish and aquatic life, the scattered signs of trouble in the inshore waters should be read for what they are--symptoms and warnings that decisions should be made now. Failure to act promptly could result in far-reaching damage, with invasion by pollutants into the hitherto undefiled waters of the open lake. With such vast potential for damage, natural resource administrators must unify in their demands for an all-encompassing program dedicated to the maintenance of high quality water in Lake Superior. Ideally, this will entail an international approach requiring the coordinated efforts of both the U. S. and Canadian Federal governments, together with the strong, unified support of Michigan, Minnesota, Wisconsin and the Province of Ontario.

The existing situation may be summarized as follows: (1) The open waters of Lake Superior still remain relatively unpolluted and of high quality, well above the U. S. approved State standards established as a result of the Water Quality Act of 1965. (2) There has been scattered but definitive water quality deterioration in the inshore and tributary stream-mouth zone which has not yet resulted in widespread demonstrable effects on fish and wildlife resources. (3) Among tributary streams, water quality ranges from very high to grossly deteriorated, with recognized adverse effects on fish and wildlife resources.

Assessment of the relationships between fish and wildlife resources of the Lake Superior Basin and water quality factors is complicated by lack of adequate knowledge and research on the interactions. Much more must yet be learned insofar as synergistic effects of various combinations of water quality relate to biological processes of aquatic plants and animals. Existing water quality standards are geared largely to insure meeting certain minimum conditions. These standards are generally based on limited information, insofar as biological needs are concerned. Additional research may demonstrate the need for redefinition and refinement of the standards to meet fish and wildlife requirements.

In the Lake Superior Basin, where existing water quality generally exceeds established standards, a false sense of security encourages seemingly small changes in the ecosystem to go unchallenged. This is particularly true when these actions have not yet been demonstrated to be adverse to the associated plant and animal communities. Non-degradation clauses have been adopted by Minnesota, Michigan and Wisconsin as part of their interstate water quality standards. In the case of Minnesota, court action is pending as the result of a company's attempt to test the legal basis of the non-degradation clause.

With a cold, oligotrophic lake such as Lake Superior, there is a tendency to disparage the danger of injecting additional increments of nutrients and heat. This is sometimes advocated on the theory that fishery productivity will be increased without altering the species composition. However, in an ecosystem as complex and large as Lake Superior, the full consequences of modifications to the basic energy system cannot be predicted. It is the position of the Fish and Wildlife Service that with the present state of knowledge and control, changes of this nature are not desirable.

The excellent quality water characterizing all of the open water environment and most of the estuarine zone supports a high value fish and aquatic life complex, unmatched for quality anywhere in the nation. The value of this fishery complex, both commercial and sport, is high. It is expected to increase as human populations increase and its scarcity value grows.

It is the position of the Fish and Wildlife Service that:

1. No reduction in the prevailing high level of water quality existing throughout most of the Lake Superior ecosystem should be permitted, even to the level of existing standards. This position is in full accord with the position already taken by Minnesota, Michigan and Wisconsin regarding non-degradation.

2. Localized situations in the inshore waters and tributary streams, where water quality levels are below established standards, should receive immediate attention to halt the input of polluting substances so as to at least meet the standards already in effect among the three states.

3. There must be greater recognition of the key role of fish and wildlife as indicators and guides in the overall basin management. This has not been sufficiently recognized in the past and change of emphasis is needed, including acceleration of necessary research and monitoring in the fish and wildlife and aquatic organism sector of water quality.

To obtain maximum benefits from an environmental research program and to assure continuity in data collection, there must be adequate coordination and exchange of information. Fishery agencies have a broad responsibility to maintain harvestable surpluses and to contribute to man's understanding and control of aquatic living resources and their environment. It seems logical that these agencies should also have a major role in the coordination and conduct of companion research related to long-term water quality changes. Without proposing any specific institutional arrangements, this function could logically be exercised through an international body such as the Great Lakes Fishery Commission. Such a group could lead the way in promoting an ecosystem approach encompassing all of the Great Lakes.

RECOMMENDATIONS

On the basis of the foregoing considerations, it is recommended that:

1. The Federal Water Quality Administration programs and State water pollution control programs recently established for the Lake Superior Basin be implemented, with the understanding that later modifications may be required as additional information becomes available.

2. Water quality guidelines proposed by the Lake Superior Water Quality Technical Committee for the open waters of Lake Superior be carefully reviewed for possible early adoption as water quality standards.

3. The "non-degradation" policy, already adopted by the three States, be strictly enforced so that the policy of no degradation may accomplish its intended purpose. It is further recommended that the international aspects of the problem be given greater recognition, by intensifying the coordination between the U. S. and Canadian governments.

4. Research programs be expanded to develop improved methods of treating wastes in major problem areas. It is further recommended that sufficient coordination be maintained with fish and wildlife interests to insure proper consideration of fish and wildlife needs.

5. Inasmuch as fishery problems related to pollution from taconite tailings in Lake Superior have the potential to become a matter of international concern, these problems be officially brought to the attention of the appropriate international agencies, for their consideration and collective action.

6. Local, State and Federal pollution laws and enforcement programs be reviewed and revised periodically, in accordance with improved techniques and changing fish and wildlife water quality standards.

7. Increased emphasis be placed on research and operations aimed toward control of agricultural pollution, including such

sources as pesticides, herbicides, fertilizers, siltation, and streambank erosion.

8. A permanent water quality monitoring system recognizing fish and wildlife needs be established, covering all segments of the basin which are important to fish and wildlife.

9. Research and monitoring programs recognize the special responsiveness of fish, wildlife and aquatic organisms to incremental long-term changes in water quality and include fish and wildlife inputs into these programs.

10. Research involving either short or long term environmental changes on Lake Superior fish, other aquatic, or wildlife forms be conducted by the fish and wildlife conservation agencies and coordinated through established institutions such as the Great Lakes Fishery Commission, with the help and cooperation of private and educational groups.

11. The level of sea lamprey control be intensified in Lake Superior and fully implemented in Lake Huron, in recognition of the top priority of this control program relative to total fishery management needs, thus assuring realization of the fish and wildlife benefits inherent in preservation of water quality in the Lake Superior Basin.

The above recommendations are intended to help preserve and develop existing resources. We recognize that implementation of these recommendations will require the strong support and active cooperation of numerous Federal and State agencies, both in the United States and Canada. In addition, numerous local agencies, private groups, industry, and the citizenry in general, all have a vital interest in this matter. The services of the Fish and Wildlife Service remain available to assist in this important effort in any way possible.

Sincerely,

R. W. Burwell, Regional Director
Bureau of Sport Fisheries and Wildlife

Ernest D. Premetz, Acting Regional Director
Bureau of Commercial Fisheries

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SUBSTANTIATING REPORT

XV.

PREFACE

This study is authorized under the Federal Water Pollution Control Act, Section 3(a) PL 660, as amended. It is one of a series of reports on six drainage basins (Illinois River, Lake Michigan, Lake Erie, Lake Huron, Lake Ontario and Lake Superior).

Authority for participation by fishery interests in such studies originates in a Congressional Act of March 3, 1887 (16 U.S.C. 744) which authorized the Commissioner, U. S. Fish Commission, to prosecute investigations and inquiries concerning the supply of food fishes of the coasts and lakes of the United States and the determination of protective, prohibitory, or precautionary measures to be adopted. Subsequent legislation, particularly the Fish and Wildlife Act of 1956, as amended, and the Fish and Wildlife Coordination Act, refined and strengthened fish and wildlife responsibilities.

Section 5 of the Fish and Wildlife Coordination Act authorizes the Secretary of the Interior, through the Fish and Wildlife Service and the Bureau of Mines, to make such investigations as he deems necessary to determine the effects of domestic sewage, mine, petroleum and industrial wastes, erosion silt, and other polluting substances on wildlife, and to make reports to the Congress concerning such investigations and/or recommendations for alleviating dangerous and undesirable effects of such pollution. These investigations shall include (1) the determination of standards of water quality for the maintenance of wildlife; (2) the study of methods of abating and preventing pollution, including methods for the recovery of useful or marketable products and by-products of wastes; and (3) the collation and distribution of data on the progress and results of such investigations for the use of Federal, State, municipal, and private agencies, and individuals, organizations, or enterprises.

Public Law 91-190, The National Environmental Policy Act of 1969, was passed "to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man." The Act places considerable responsibility upon all Federal agencies to, among other things, "attain the widest range of beneficial uses of the environment without degradation, risk to health or safety, or other undesirable and unintended consequences."

In keeping with these authorities, this report has been prepared by the Bureau of Commercial Fisheries and the Bureau of Sport Fisheries and Wildlife.

The analyses in this report are based on statistical records, field investigations, published material, and the experience and judgment of a staff that has worked with the resource for many years. While far from complete for a resource base as large and complex as the Lake Superior Basin, this background is considered sufficient for indicating the dimensions of the resource and for making reasoned judgments on trends, problems, and future requirements. A list of references is attached to facilitate more detailed inquiry and, where appropriate, the text has been annotated selectively.

ACKNOWLEDGMENTS

The published studies and surveys used in preparing this report are credited in the list of references. In addition, the encouragement, interest, basic data, ideas, and assistance contributed by the following agencies have helped greatly in preparing this report:

Federal Agencies

Bureau of Outdoor Recreation
Corps of Engineers
Federal Water Quality Administration
Geological Survey
Public Health Service

Foreign Agencies

Ontario Department of Lands and Forests
Canadian Department of Fisheries and Forestry

International Agency

Great Lakes Fishery Commission

State Agencies

Michigan Department of Natural Resources
Michigan Water Resources Commission
Minnesota Department of Conservation
Wisconsin Department of Natural Resources

DESCRIPTION OF THE BASIN

GENERAL

Consideration of habitat (environmental) factors is essential for an adequate understanding of fishery potential and population dynamics. Water quality factors (the chief interest of the comprehensive study) are closely related to such consideration. Knowledge of the Lake Superior Basin habitat base is far from complete. Due mainly to its great size, it is only within the past decade that Lake Superior has been subjected to extensive limnological investigation. Unfortunately, reports involving critical observations and scientific investigations of its limnological phenomena are not numerous. Those that are available are widely scattered in the various scientific journals and documents. Investigations have generally been concerned with physical limnology such as lake level fluctuations, lake temperature, lake currents, seiches, and tides. Chemical, physical and biological analyses have been confined to limited areas.

THE GREAT LAKES

The five Great Lakes and their connecting waters have a combined surface area of over 95,000 square miles and a total drainage area of 295,200 square miles (Table 1). They form the largest group of lakes in the world. The geographical area covered by this study, however, comprises only the United States portion of the Great Lakes and their watersheds, plus the Illinois River and its drainage basin. The latter basin adds another 30,000 square miles.

Table 1.--Physical Data of Great Lakes System[1]

Lake	Length (Mile)	Breadth (Mile)	Water Area (Sq. Miles) U.S.	Canada	Total	Average Surface Elevation Since 1860 (feet)	Maximum Depth (feet)	Mean Depth (feet)	Drainage Area (sq.mi.)
Superior	350	160	20,700	11,120	31,820	602.20	1,333	487	80,000
Michigan	307	118	22,400	-	22,400	580.54	923	276	67,860
Huron	206	183	9,110	13,900	23,010	580.54	750	195	72,620
St. Clair	26	24	200	290	490	574.88	21	10	7,430
Erie	241	57	4,990	4,940	9,930	572.34	210	58	32,490
Ontario	193	53	3,600	3,920	7,520	246.03	802	283	34,800
Totals:			61,000	34,170	95,170				295,200

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[1] Adapted from Beeton and Chandler "St. Lawrence Great Lakes" LIMNOLOGY IN NORTH AMERICA - University of Wisconsin Press - 1963.

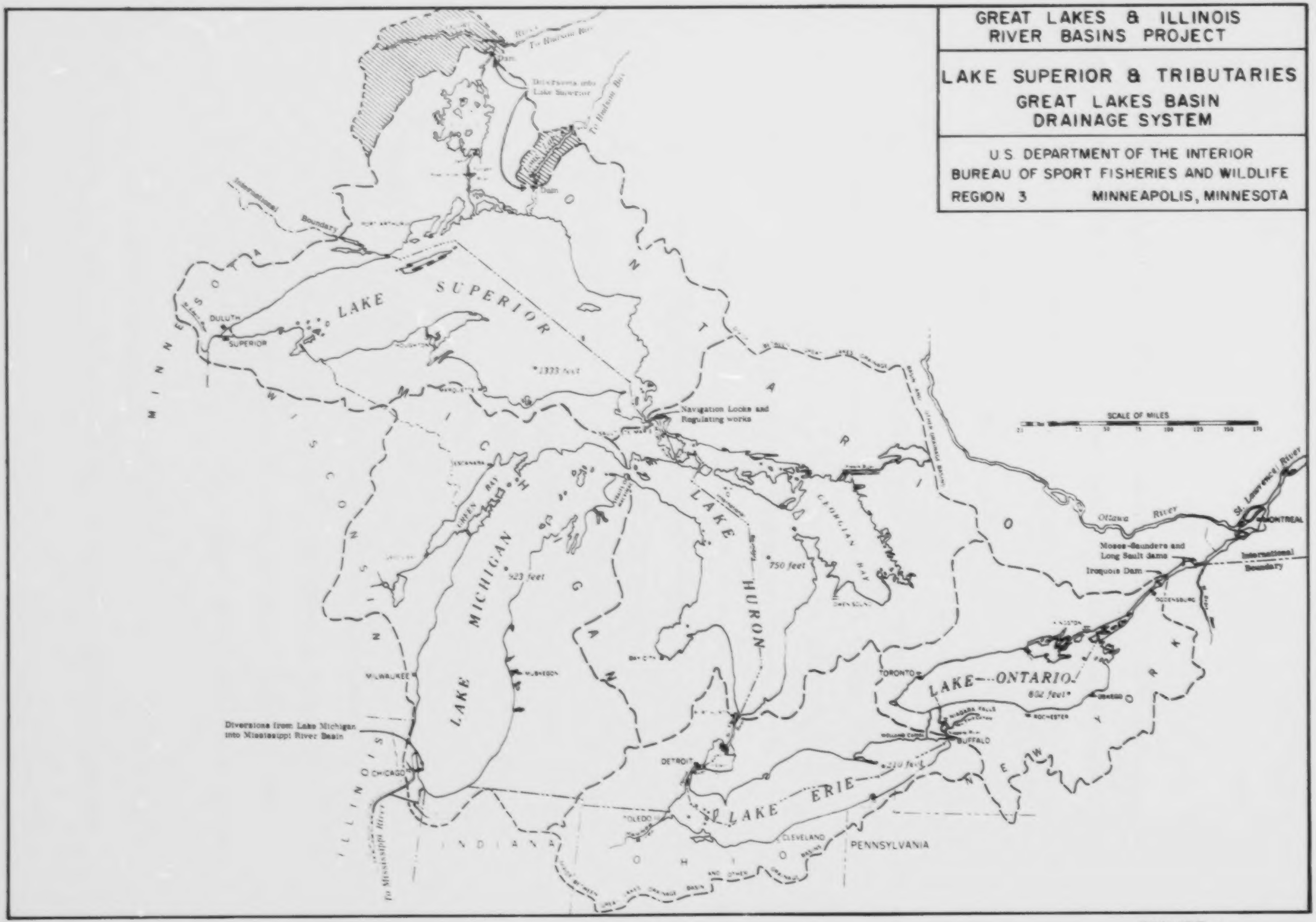
Figures 1 and 2 orient the reader to pertinent physical features of the Great Lakes Basin.

LAKE SUPERIOR

Morphometry.--Lake Superior forms a wide, northerly convex crescent stretching 350 miles, with a width of 160 miles, and covering 31,820 square miles. It is not only the largest of the Laurentian Great Lakes but is also the largest body of fresh water in the world.

Lake Superior is also the deepest of the Great Lakes (Figure 2), with a maximum depth of 1,333 feet, 731 feet lying below sea level, and a mean depth of 487 feet. The western two-thirds of the lake has a relatively smooth basin, with depths of over 590 feet; the eastern third has a ridge and trough topography where depths exceed 490 feet over the ridges and 820 to 1300 feet in the troughs. Only 17.5 percent of the lake is shallower than 100 feet, while 51 percent of the lake is deeper than 420 feet (Table 2 and Figures 3 and 4; Long & Schueler, 1968). The only important stretches of shallow water lie in the Apostle Island region, Whitefish Bay, and in the bay region of the north shore. In addition, the lake contains 54 percent of the total volume of the Great Lakes, with 2,927 cubic miles of water.

The principal islands are Isle Royale, Michipicoten and the Apostle Island group (Figure 5). The shoreline, including the islands, totals over 2,800 miles. The French originally named the


To Hudson Bay
Dam
Diversions into Lake Superior
To Hudson Bay
Dam
International Boundary
PORT ARTHUR
MINNESOTA
DULUTH
SUPERIOR
LAKE SUPERIOR
1333 feet
ONTARIO
Navigation Locks and Regulating works
WISCONSIN
MICHIGAN
GREEN BAY
LAKE MICHIGAN
923 feet
MILWAUKEE
MUSKEGON
LAKE HURON
750 feet
GEORGIAN BAY
OWEN SOUND
BAY CITY
SCALE OF MILES
Ottawa River
St. Lawrence River
MONTREAL
Moses-Saunders and Long Sault dams
Iroquois Dam
International Boundary
OGDENSBURG
KINGSTON
TORONTO
LAKE ONTARIO
602 feet
ROCHESTER
NIAGARA FALLS
WELLAND CANAL
BUFFALO
NEW YORK
Diversions from Lake Michigan into Mississippi River Basin
CHICAGO
ILLINOIS
To Mississippi River
INDIANA
DETROIT
TOLEDO
LAKE ERIE
572 feet
CLEVELAND
OHIO
PENNSYLVANIA

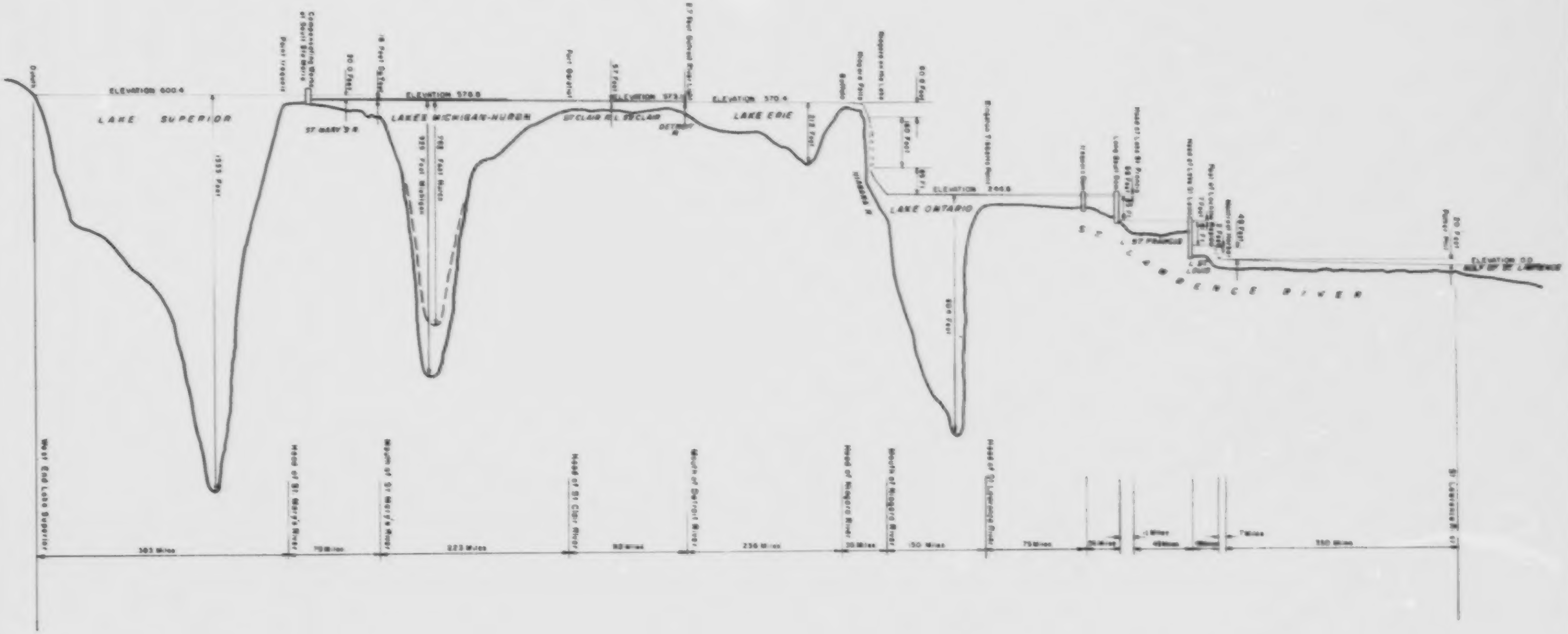
GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

LAKE SUPERIOR & TRIBUTARIES
GREAT LAKES BASIN
DRAINAGE SYSTEM

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF SPORT FISHERIES AND WILDLIFE
REGION 3 MINNEAPOLIS, MINNESOTA

8

FIGURE I



GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

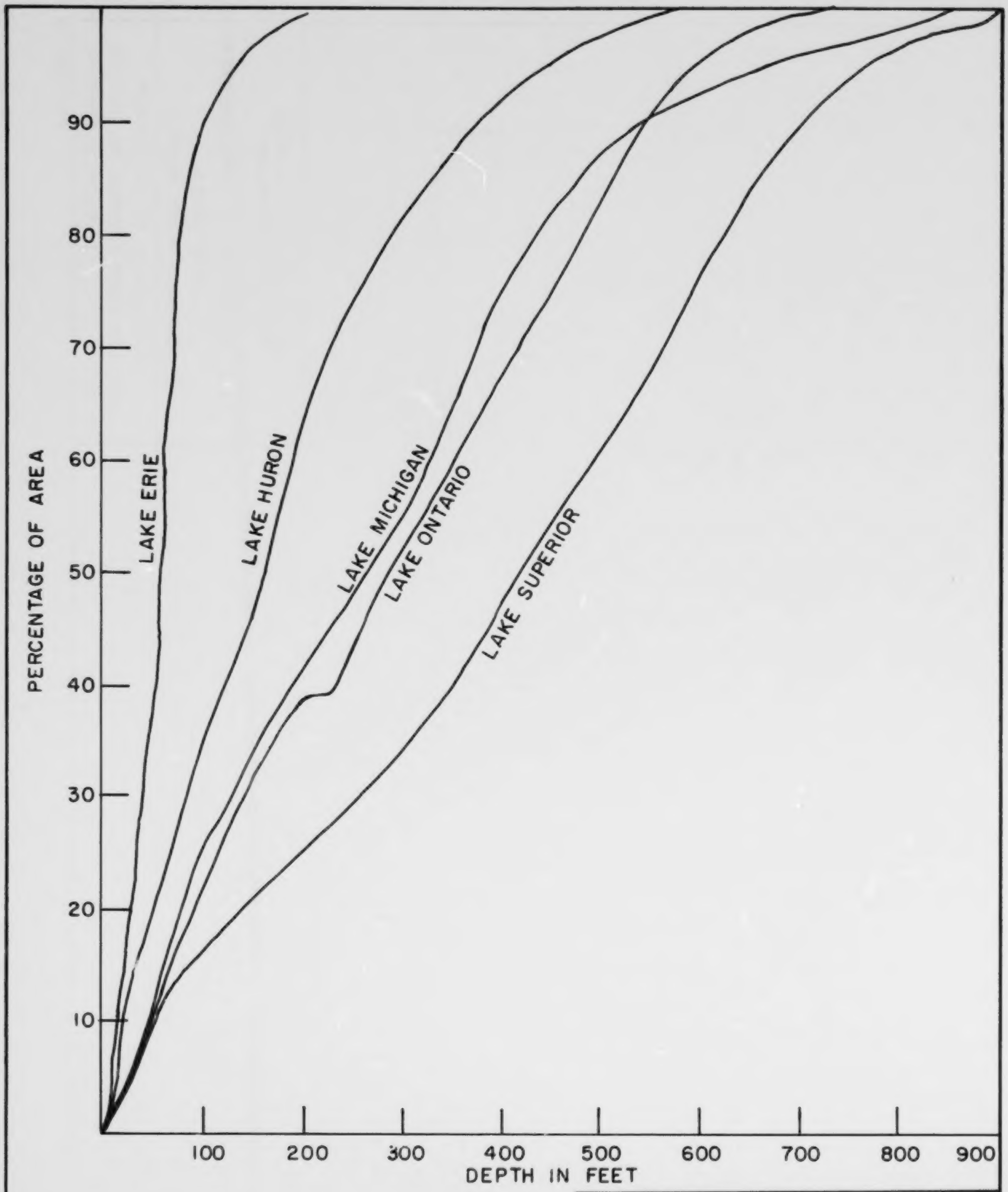
LAKE SUPERIOR & TRIBUTARIES
GREAT LAKES

ST. LAWRENCE RIVER PROFILE

U. S. DEPARTMENT OF THE INTERIOR
BUREAU OF SPORT FISHERIES AND WILDLIFE
REGION 3 MINNEAPOLIS, MINNESOTA

E.M.P. 690313

FIGURE 2



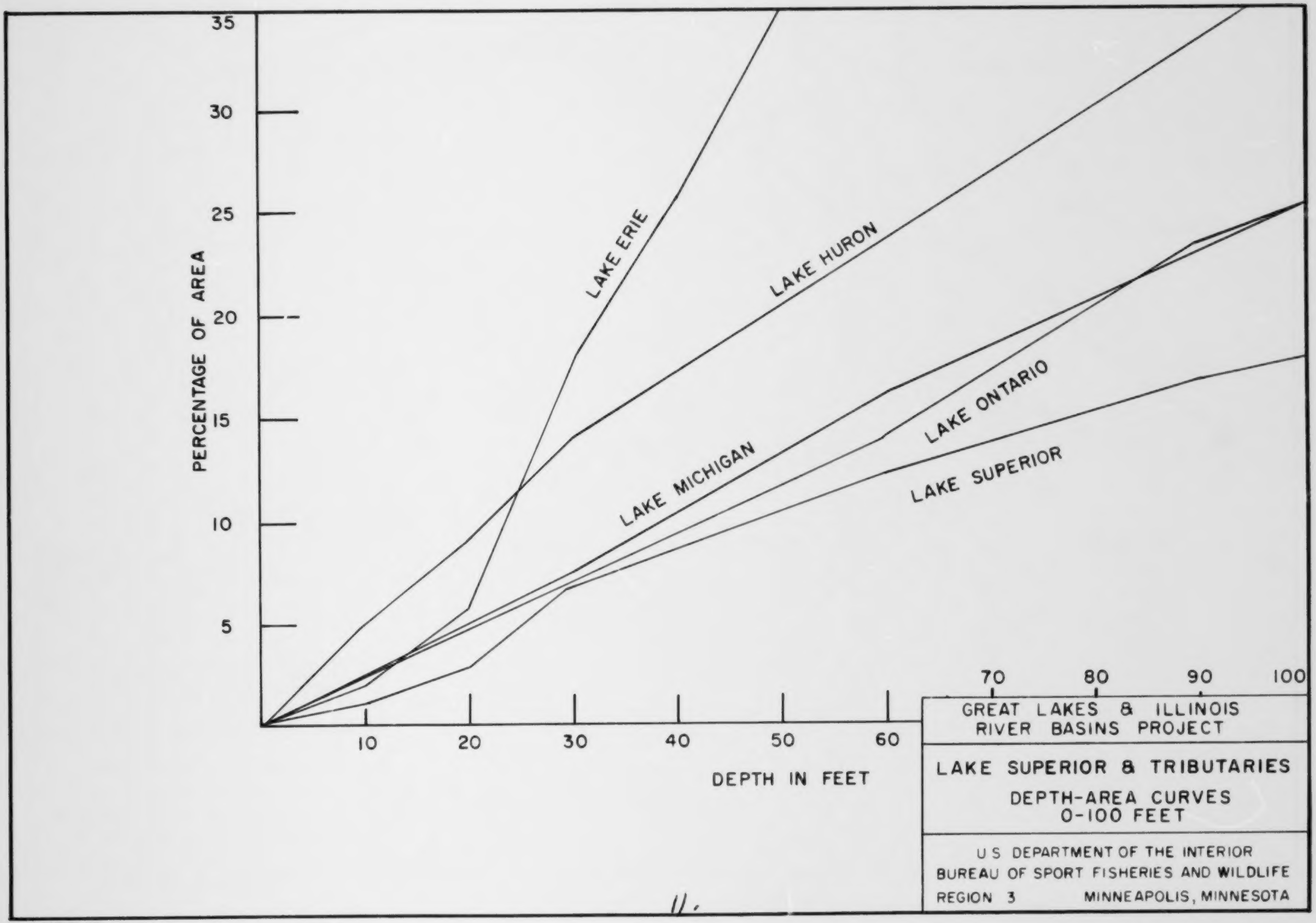
GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

LAKE SUPERIOR & TRIBUTARIES

DEPTH-AREA CURVES
0-900 FEET

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF SPORT FISHERIES AND WILDLIFE
REGION 3 MINNEAPOLIS, MINNESOTA

FIGURE 3



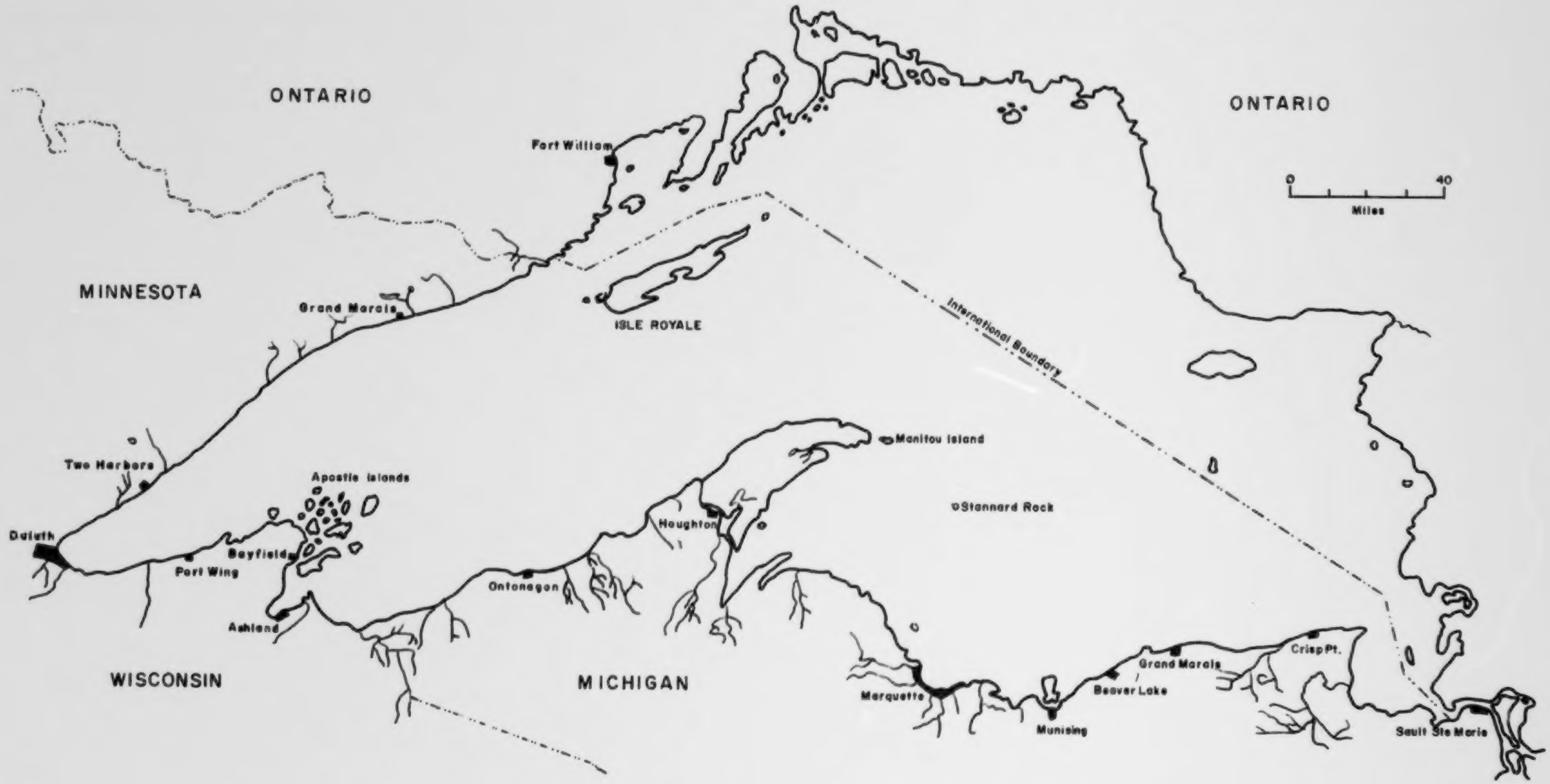
GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

LAKE SUPERIOR & TRIBUTARIES

DEPTH-AREA CURVES
0-100 FEET

U S DEPARTMENT OF THE INTERIOR
BUREAU OF SPORT FISHERIES AND WILDLIFE
REGION 3 MINNEAPOLIS, MINNESOTA

FIGURE 4


ONTARIO
ONTARIO
MINNESOTA
WISCONSIN
MICHIGAN
Fort William
Grand Marais
ISLE ROYALE
International Boundary
0
40
Miles
Two Harbors
Apostle Islands
Duluth
Port Wing
Bayfield
Ashland
Ontonagon
Houghton
Manitou Island
Stannard Rock
Marquette
Munising
Beaver Lake
Grand Marais
Crisp Pt.
Sault Ste Marie

GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

LAKE SUPERIOR & TRIBUTARIES

MAP OF LAKE SUPERIOR

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF SPORT FISHERIES AND WILDLIFE
REGION 3 MINNEAPOLIS, MINNESOTA

FIGURE 5

Table 2.--Depth-Area Percentages for Lake Superior

Depth In Feet	Percentage	Depth In Feet	Percentage
10	1.09	480	58.92
20	2.97	510	63.92
30	6.88	540	68.30
60	12.35	570	72.36
90	16.73	600	77.20
120	19.07	630	79.39
150	21.73	660	84.08
180	24.07	690	87.52
210	26.10	720	90.02
240	28.29	750	92.83
270	30.43	780	95.02
300	33.76	810	96.90
330	37.98	870	97.53
360	43.29	900	98.78
390	47.67	990	99.41
420	50.95	1332	100.00
450	54.86		

lake "Lac Superieur", meaning "upper lake". It has the highest elevation of any of the Great Lakes.

The Lake Superior basin lies almost wholly on igneous and metamorphic rocks of the Pre-Cambrian era of the Canadian Shield, with limited areas of Cambrian sandstones adjoining the south shore of the lake east of Marquette, Michigan, and in the Bayfield Peninsula-Apostle Island region. Lake Superior is unique among the Great Lakes in that it is for the most part surrounded by high ground with rocky shores. In the south there are broad stretches of sand, gravel, and clay. Most of the bottom in the deeper parts is clay. At an estimated 20,000 years (Hough, 1958) it is relatively young in geologic terms. All of these factors have important effects on the lake's ecosystem.

Hydrology.--There are over 1,000 streams tributary to Lake Superior. However, due to the limited size of the drainage basin, none of these are of any great length or magnitude. The northern shore has a larger percentage of the drainage area than the southern and this is reflected in the relative size of the streams, with the larger ones entering from the north. The largest is the Nipigon River, which flows from Nipigon Lake. The second largest is the St. Louis River, emptying at Duluth. Forty percent of Lake Superior Basin's 80,511 square mile drainage area is occupied by the lake. Average annual rainfall of 28.2 inches in this basin is less than that of any of the other Great Lakes basins.

The lake's outlet is to Lake Huron via the St. Marys River* at Sault Ste. Marie, Michigan. Mean annual discharge at Sault Ste. Marie is 73,300 cubic feet per second. This discharge is a very small percentage of the volume and it has been estimated that the average retention time of water is 189 years (Rainey, 1967).

Lake surface elevation above mean sea level has ranged from a high of 604.1 feet in 1869 to a low of 600.0 feet in 1926, with an average of 602.2. Normally the lake level varies slightly more than one foot annually. Irregularities in the long-term levels suggest that there may be other cycles occurring simultaneously with the annual cycle. Perhaps this is the result of reinforcement and interference between cycles of various periods (Ayers, 1962). However, since 1922, the levels of the lake and the discharge through the control works at the Sault locks have been controlled for hydroelectric power and navigation.

Thermal Conditions.--The thermal conditions of Lake Superior are the least well known of any of the Great Lakes. Ice forms during the winter months, but it very seldom completely covers the lake. Four stages in the pattern of ice distribution have been identified: "Stage 1 - initial ice formation along the shoreline, principally in harbors and bays from mid-December to mid-January;

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*For a discussion of the St. Marys River habitat base, see the Lake Huron report of this series.

Stage II - formation of a wide zone of ice cover around the margins of the lake from mid-January to mid-February;
Stage III - ice formation in mid-lake locations creating a drifting ice pack from mid-February to mid-March; and Stage IV - the decay of the ice cover which takes place from mid-March to late April." The average ice thickness during the 1952-1966 period ranged from 30 cms. at Ontonagon, Michigan, to 79 cms. at Port Arthur, Ontario (Marshall, 1967). Along the northern edge of Keweenaw Peninsula ice builds up to depths of 10 meters or more. Floating ice blown to shore causes these buildups.

Since the lake forms an incomplete ice cover, during severe winters it is exposed to drastic cooling and strong wind mixing. In January, the mean air temperature at land stations is about 13 degrees F. lower than for the other Great Lakes. Therefore, a large thermal capacity is exposed to winter's cold and the lake has a low annual temperature. Throughout most of the winter and spring, the effect of deep mixing is especially apparent in Lake Superior. Homothermous water around 2^{o}C. can occur to a depth of 600 feet, but stratification does occur. By late winter and into May, the bottom of the epilimnion is about 450 feet. Well-defined stratification is evident by mid-July, when a thermal discontinuity usually develops throughout some sections of the lake. Occasionally there are sharp temperature gradients within a 10 foot vertical zone, sometimes approaching 15^{o}C., but phenomena of this nature are generally temporary and local. The lower level of the epilimnion by mid-summer is around 45 feet, with the thickness varying with time and place. The temperature of the deeper water remains near 4°C. throughout the year.

There are several references in the literature indicating that in the central parts of the lake upwellings of cold water during the summer months are common. Ragotzkie and Bratnick (1965) have postulated a model explaining the observed persistence of these cold areas as a balance between radiational heating of the surface layers and upwellings of cold water from below. A dynamic equilibrium between the upwelling of cold hypolimnion water and the absorption of incoming solar energy would account for the cold pools, while the upwelling represents the conversion of kinetic to potential energy. Wind stress supplies the necessary kinetic energy. Other authors state that Isle Royale and the Keweenaw Peninsula contribute to this upwelling, but there is no evidence that bottom topography influences the surface distribution of temperatures (Anderson and Rodgers, 1963).

Rodgers (1965) postulated the formation of a thermal bar in the Great Lakes. In the spring when the main body of the lake is isothermal a horizontal stratification occurs along the shoreline. In the spring the inshore waters warm more rapidly than the main body of the lake does, causing a density interface, the "thermal bar", to develop at the 4°C. isotherm or temperature of maximum density. With the development of a "thermal bar" a convective circulation is set up which results in sinking along the interface. As the warming progresses the "thermal bar" migrates out into the lake. Such a temperature differential hinders mixing between inshore and offshore water and would affect the dispersion of runoff and pollutants near the shore.

Currents.--The circulation of water masses in Lake Superior involves surface currents, horizontal deep currents, and vertical water movements. The three types are variously related temporally and spatially and have varying degrees of coexistence.

Lake Superior, being oriented on a west to east axis, is swept almost lengthwise by the resultant winds of the area. Surface currents are primarily wind-controlled and respond to wind shifts. The basic current patterns are, at best, poorly known. The prevailing winds produce a dominant west to east flow along the south shore during the summer months and it is generally concluded that the surface circulation is essentially counterclockwise around the perimeter of the lake. It also appears that some of the counterclockwise flowing water near the center of the lake cuts downward from east of Isle Royale towards the tip of the Keweenaw Peninsula, thus taking a short cut in its trip around the lake. The speed of these currents generally ranges from 4-10 miles per day. During the summer period of stratification, horizontal surface currents and horizontal deep currents occur simultaneously. At 50 feet the horizontal current speeds are about 1/2 the speed of the surface currents, while at a depth of 200 feet the speed is about one-fourth.

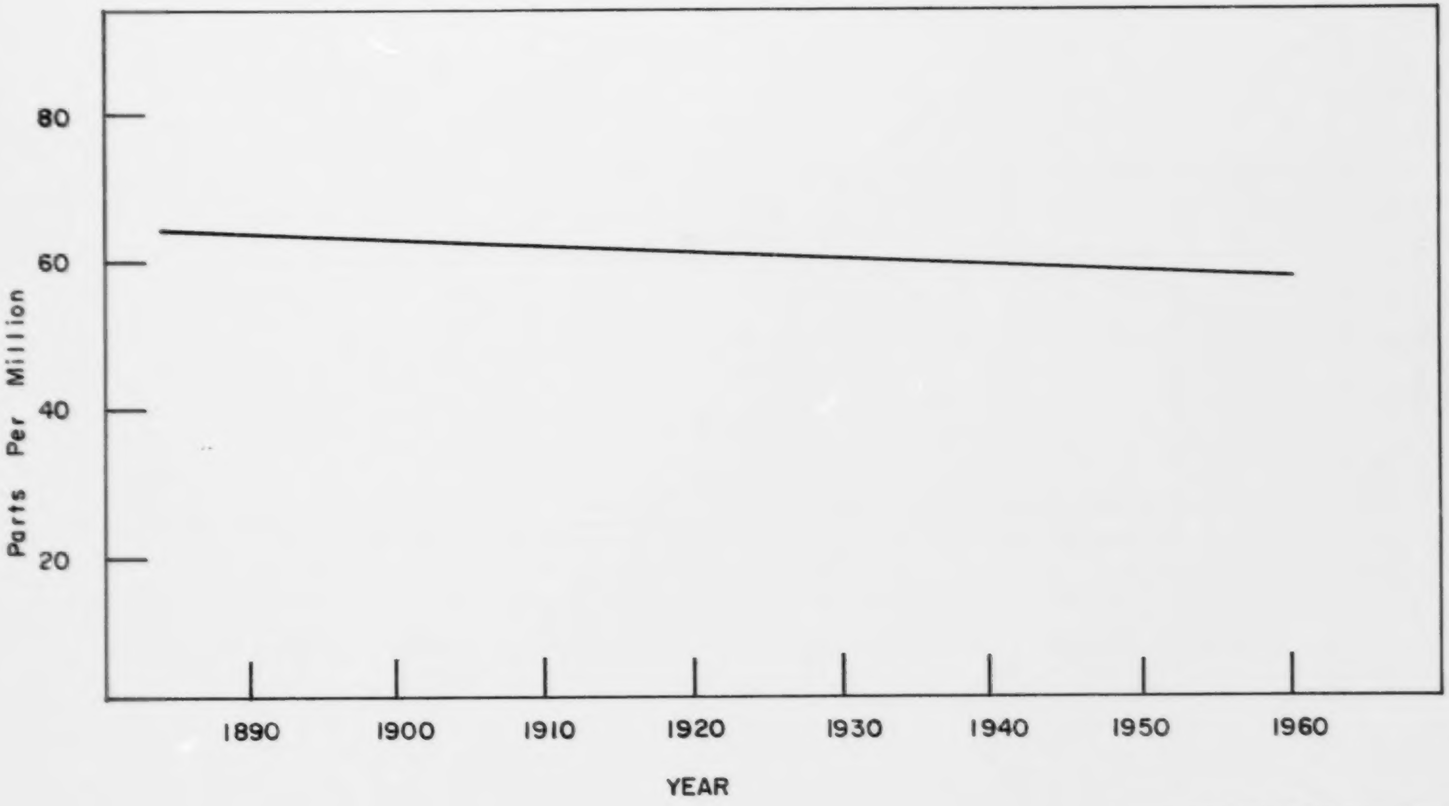
During this period, the horizontal surface currents and horizontal deep currents are connected by vertical water movements in the major sinkings and upwellings. Though the complexities and interactions of these currents are very poorly known, there are indications that major sinkings can depress the thermocline and that major upwellings can raise hypolimnion water to the surface. Downward movement at major sinkings, along with the upward movement at major upwellings, causes a hydraulic gradient to develop which tends to move water from areas of sinking to areas of upwelling. In this regard because of the Coriolis Force the result flow would tend to be parallel to the gradient rather than directly down the gradient. Wind or barometric change supplies kinetic energy to the lake which moves the surface waters about, thus causing tilting and oscillation of the thermocline (Ayers, 1962).

During the period from fall to spring the vertical circulation becomes more pronounced. In the fall the lake's surface water cools and when it is reduced to a temperature of about 6°C. the thermal stratification is weaker so that it is easily upset by the wind. When this happens the lake becomes essentially isothermal. As the season progresses the surface waters continue to cool but the surface temperatures will not be below the temperature (4°C.) of maximum density. Because the density difference between the surface waters is not great, mixing caused by the winds is effective to greater depths in winter than in summer. As a result no thermal stratification is found in early winter. By late winter, however, a thermocline is established at depths of about 450 feet. From this time on the vertical circulation is confined to the eplimnion. Surface waters driven across the lake by the wind are replaced by deeper water. Little data is available on the winter circulation patterns.

Light Penetration and Transparency.--The open waters of Lake Superior are among the clearest waters in the world. There are inshore areas, however, where this clarity is diminished. This generally occurs near the mouth of tributary streams, where suspended solids cloud the waters. There is also a "green water" phenomenon that occurs near the Silver Bay area. This appears to be associated with taconite processing operations and with incoming sediments apparently associated with some tributaries.

Chemical Characteristics.--Lake Superior is the only one of the Great Lakes which is in essentially its original chemical condition, having remained largely unchanged since 1886, the period of record. The waters are also essentially homogenous throughout. The concentration of most ions differ only slightly between areas and have only limited seasonal and vertical variations.

The major chemical constituents of the open lake waters are: calcium (12.4 ppm), magnesium (2.8 ppm), potassium (0.6 ppm), sodium (1.1 ppm), total alkalinity (46 ppm $CaCO_3$), chloride (1.9 ppm), sulfate (1.2 ppm), silica (5.0 ppm), total phosphorus (5 ppb PO_4), pH (7.4), specific conductance (78.7) and total dissolved solids (59 ppm). Table 3 gives a summary of these and other ions in Lake Superior, while Figures 6 and 7 show the change of total dissolved solids and some selected ions over the years.



GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

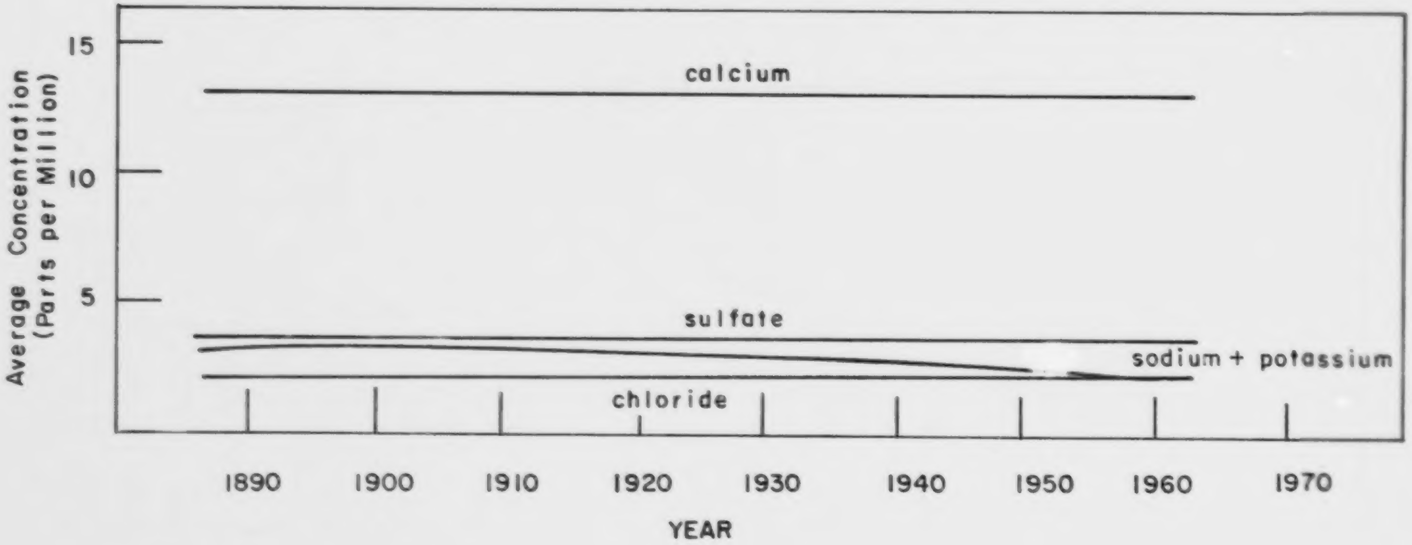
LAKE SUPERIOR & TRIBUTARIES

TOTAL DISSOLVED SOLIDS
(FROM BEETON, 1965)

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF SPORT FISHERIES AND WILDLIFE
REGION 3 MINNEAPOLIS, MINNESOTA

FIGURE 6

21



GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

LAKE SUPERIOR & TRIBUTARIES
CHEMICAL CHANGES
(BEETON, 1965)

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF SPORT FISHERIES AND WILDLIFE
REGION 3 MINNEAPOLIS, MINNESOTA

FIGURE 7

Table 3.--Average Chemical Characteristics of Lake Superior Waters.*

Characteristic	Amount	
Total Phosphorus		
Open Lake	5	ppb
South Shore	10-15	ppb
Average	13.6	ppb
Calcium	12.4	ppm
Magnesium	2.8	ppm
Potassium	0.6	ppm
Sodium	1.1	ppm
pH	7.4	
Specific Conductance	78.7 k_{18}x 10^{6} 0 18° C	
Total Dissolved Solids	59	ppm
Total Alkalinity ($CaCO_3$)	46	ppm
Bicarbonate	59	ppm
Carbon Dioxide		
Surface	0.6-2.2	ppm
Depth	0.7-8.5	ppm
Sulfate	1.2	ppm
Silica	5.0	ppm
Nitrogen	0.15	ppm
Chloride	1.9	ppm
Turbidity		Trace
Free Ammonia	0.1	ppm
Iron	0.062	ppm

*Unweighted averages.

The indicated slight decrease in the total dissolved solids is not significant and concentrations have remained at approximately 59-60 ppm throughout the years. Calcium, chloride and sulfate concentrations have also remained the same since 1886. The calcium, magnesium, sodium ratio (12:3:1) has varied little. Few fresh water lakes have this consistency. The slight indicated change in sodium and phosphorus concentrations is probably due to changes in analytical techniques and not due to actual physical changes in the ion concentrations themselves.

Dissolved oxygen is normally near saturation and at times reaches supersaturated conditions. Generally the dissolved oxygen content is near saturation at all depths.

The Duluth-Superior area tends to have higher concentrations of some ions. Sulfate may range from 4.9 to 12.5 ppm and it appears that Lake Superior may gain appreciable quantities of nitrogen from surface runoff in this area (Putnam & Olson, 1960). However, the water is rapidly diluted and it does not retain these high values for any distance offshore.

With the possible exception of dissolved N_2, this element in Lake Superior is found primarily as fully oxidized nitrate. During the summer months, the surface waters have a somewhat lower concentration of nitrate than the hypolimnion layers. This may be due to utilization of this material by plankton. During the fall mixing, it is presumed that the surface nitrate is replenished from below.

However, it is entirely possible that nitrification in surface water may also play a significant role in restoring nitrate levels (Putnam & Olson, 1960).

Trace element studies of the sediments of Lake Superior found surface concentrations of manganese, copper, lead and zinc, which indicated active sediment-water exchange of these elements. The manganese transfer is largely a precipitation mechanism, whereas absorption is responsible for the transfer of copper and zinc. The surface concentrations of these elements can probably be accounted for by an increase in the rate of chemical sedimentation coupled with a decrease in the rate of physical sedimentation (Nussman, 1964).

Bromine is bound in the organic fraction of the sediments and increases in concentration upward towards the sediment-water interface over the span of a few meters. Strontium is found in several sediments' constituents, both detrital and non-detrital, inorganic and organogenic, in varying concentrations and varying strontium-calcium ratios (Nussman, 1964).

Plankton.--The plankton of Lake Superior is very sparse and dominated by forms characteristic of cold, deep lakes. Recent studies continue to show that the diatoms are the most abundant plankton groups and the lake is predominantly chrysophytes. Earlier impressions that Dinobryon is usually the most abundant genus have not been confirmed (Davis, 1966).

The most abundant forms of phytoplankton are: *Asterionella formosa*, *Dinobryon* sp., *Synedra acus*, *Cyclotella* sp., *Tabellaria fenestrata* and *Melosira granulata* (Beeton, 1965).

Eddy (1943) lists the following zooplankton as common: rotifers - *Keratella cochlearis* and *Kellicottia longispina*; cladocerans - *Daphnia longispina* and *Bosmina longirostris*: copepods - *Diaptomus minutus*, *D. sicilis*, *Epischura lacustris*, *Limnocalanus macrurus* and *Cyclops bicuspidatus*.

Benthos (Bottom) Organisms.--There have been very few studies of the benthic invertebrates and their ecology in Lake Superior. Between 1871 and 1966, there were no published accounts on this subject. Hiltunen (1969) recently completed a study of the benthic organisms in the Apostle Island region of the lake. After comparing his results and other published accounts on Lake Superior benthos with studies on the other Great Lakes, he concluded that the invertebrate fauna of western Lake Superior was similar to that of the other lakes. However, there is apparently a lower density of the amphipod *Pontoporeia affinis* in the Apostle Island region than in Lakes Michigan and Ontario. Among other groups of organisms, species and specific environmental relationships were similar to those reported for the other Great Lakes.

The benthic communities of the Great Lakes are composed of a young fauna. Pleistocene glaciation removed preglacial components of the region. As the ice sheets retreated, the newly formed lakes became populated both by species then living in the preglacial lakes and by those species that migrated in the wake of the melting ice. This occurred as recently as 4,000 to 8,000 years ago. With such a short period of time, the rich fauna found in more ancient lakes has not had the opportunity to develop (Henson, 1966).

The amphipod (*Pontoporeia affinis*), the opposum shrimp (*Mysis relicta*) and the midge-fly genus (*Hydrobaenus*) are listed as the dominant members of the Lake Superior bottom fauna (Beeton, 1965).

Productivity.--Lake Superior is the least productive of the Great Lakes. Putnam and Olson (1961) have compared it in productivity to the highly oligotrophic regions of the ocean. Many reasons for this low productivity have been previously stated in this section and are perhaps best summarized in the following statement by Dr. J. W. Moffett of the Bureau of Commercial Fisheries (Bureau of Commercial Fisheries, 1966):

> "Lake Superior is the largest body of fresh water in the world (20,364,800 acres). It is also one of the cleanest. Because of this cleanliness its biological productivity is low. Pure water produces nothing biological because in its pure state water is just another chemical compound, essential to life but not a generator of life. Life in water is determined by the contaminants contained therein, since organisms depend on such substances for nutrition and other necessary functions. The contaminants that make for productivity include many organic and inorganic chemicals, heat, and sunlight. Various physical features, including location and character of the container or basin in which the body of water is situated, also influence materially the tempo of life and the rate of use of these necessities for life. Lake Superior is not only large but it is also very deep (average depth 487 feet). It is located in an area that contributes little to its organic enrichment

> or thermal content. Its basin lies almost entirely on the Canadian shield--a massive granitic area that is very old and deficient in soluble minerals, organic material, and remains of previous organisms. Repeated glaciation has swept the drainage of soil and sedimentary accumulations. The most recent of these occurred about 10 thousand years ago--just yesterday, geologically speaking. The lake is also cold throughout most of its depth. In many years, it seldom exceeds 45°F. at the surface except in sheltered bays and coves. Below its immediate surface the lake water stays between 32° and 39°F. the year round.
>
> "Phytoplankton, which is the key to conversion of organic materials and chemicals to usable life forms, is so low in Lake Superior that samples of water have to be concentrated five times for meaningful comparative measurement of productivity. Even this concentration is insufficient to measure photosynthesis by the light and dark bottle techniques usually satisfactory when testing more productive lakes."

Conditions are not completely uniform throughout the lake, however, and certain regions on the south shore have been found to be more productive than others. The dry weight of plankton per cubic meter in the Apostle Island region was found to be 4-5 times greater than sampled areas in the western part of the lake. Other areas of high productivity are the region southeast of the Keweenaw Peninsula and east of Grand Marais, Michigan, and the northwest shore of the Keweenaw Peninsula (Beeton, 1959). A localized zone of enrichment occurs near the Duluth-Superior region and it extends several miles out into the lake before becoming diluted and losing its identity (Putnam & Olson, 1961). These and other studies indicate that phosphorus is probably the limiting factor.

An analysis of commercial fish production per acre also finds Superior the least productive of the Great Lakes. Since 1879, the lake has averaged between 0.8 and 0.9 pounds per acre per year.

INLAND AREAS

Tributary Streams.--Lake Superior receives drainage from approximately 1,000 rivers and streams. The largest tributary is the Nipigon River, which drains Lake Nipigon and enters from the north. Other important rivers on the Canadian shore are the Pigeon (International Boundary), Kamistkwia, Pic, Montreal, White and Michipocoten. The St. Louis River, discharging at Duluth, is the second largest tributary. No other large rivers enter from the south.

Studies by the Bureau of Commercial Fisheries on tributary streams, in conjunction with sea lamprey control, found that the water quality of streams was largely related to the geological characteristics of the land through which they flowed. The concentration of aluminum, copper and iron was found to vary little with flow or season; however, the concentrations of magnesium, calcium chloride, total alkalinity, total hardness and conductivity varied with the flow, temperature and season. The lowest values were during the spring runoff and heavy rains, with the highest during low water in late summer and the colder periods of winter. Concentrations of tanninlike and ligninlike compounds* were highest during the spring runoff and other high water periods and were lowest during freeze-up when surface runoff was minimal. The pH values were highest from June to September and the lowest during the spring runoff. Phenolphthalein alkalinity was detected primarily in the summer and coincided occasionally with low flows just before the spring thaw.

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*Compounds which are basic to the structure of woody plants and are released when these plants decay.

In addition to the effects of the basic topography and geology, each stream was also affected by elevation of the water table, turbulence, shade from vegetation, and variable influences of their tributary streams. Man affects the water quality through industrial and domestic wastes, changes in land use and the impoundment of water behind dams.

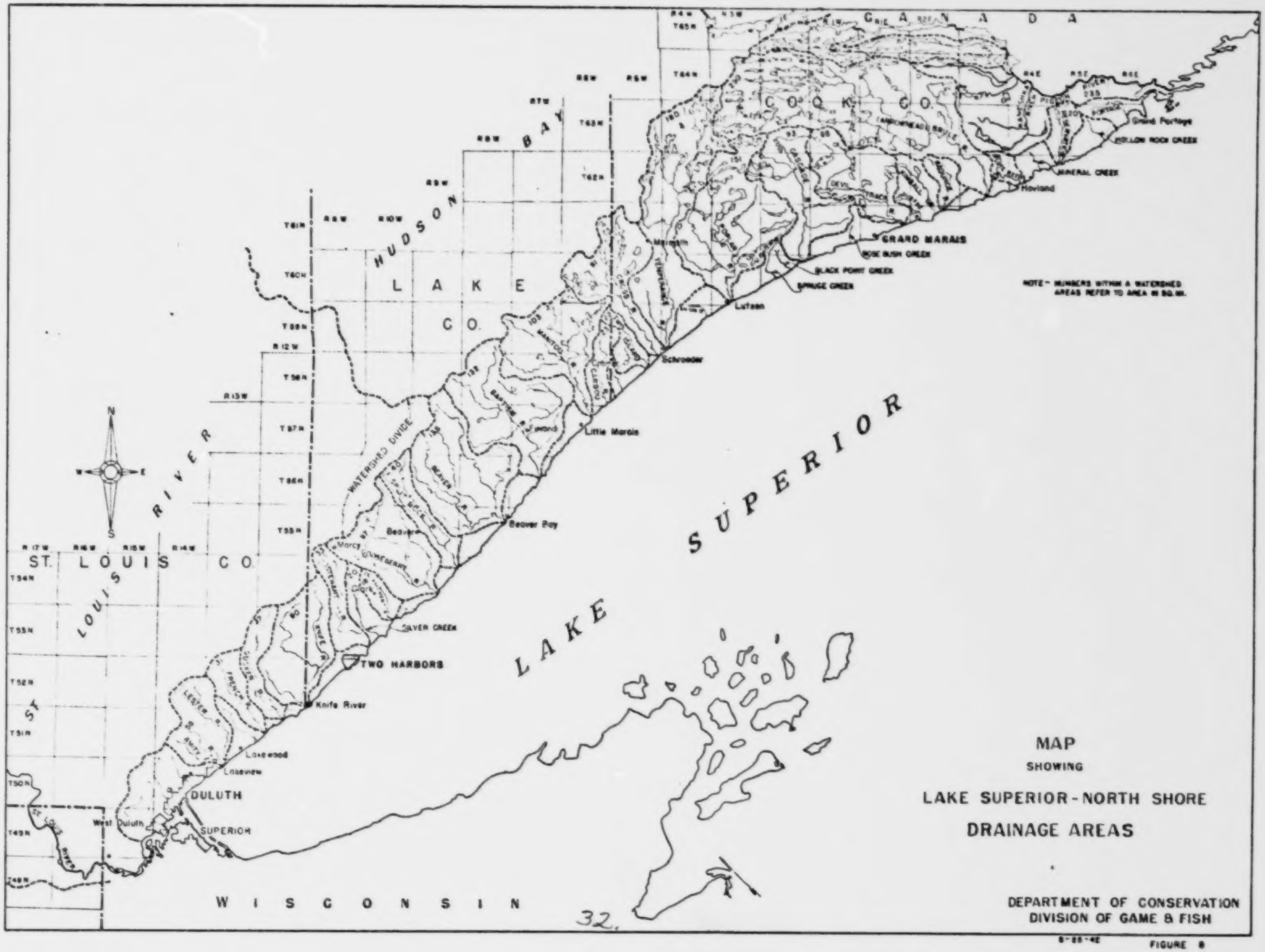
There was little change between the characteristics of streams in the western arm of the lake in 1958 and 1959 and similar studies conducted in 1944. Lake Superior is enriched by impressive amounts of nutrients, which enter by way of tributary streams (Putnam & Olson, 1960).

Land Areas.--Secondary forests are the principal type of cover over the Lake Superior watershed. These forests are mixed hardwoods and conifers, with birch and aspen the principal species. The original stands of timber were clear cut or destroyed by fire in the late 1800's and early 1900's over most of the watershed. The fires were especially damaging because they burned out many of the water retaining swamps and muskegs. Thus, regular flow of many tributaries is dependent almost entirely upon regular precipitation throughout the season.

The North Shore watershed (excluding the St. Louis River watershed) covers approximately 2,400 square miles and is made up of a narrow strip of land 15 to 25 miles wide (Figure 8). The watershed slopes steeply toward the lake, with some streams dropping as much as 1,400 feet from their sources in a very short distance. Numerous rock outcrops and the rapid rate of descent cause many waterfalls and rugged cataracts, especially near Lake Superior (Smith & Moyle, 1943).

The St. Louis River Watershed encompasses 3,600 square miles in an area generally north and west of Duluth, Minnesota (Figure 9). Seventy to eighty percent of the watershed is covered by mixed conifer-hardwood forests, with the balance in agriculture, mining and residential areas. The relief over most of the watershed is low, resulting in slow streams. The water takes on a rusty brown color from the decaying vegetation in the many swamps, but this has little effect on fish populations.

The remaining 18,300 square miles of the Superior Watershed are in the Wisconsin and Michigan portions of the south shore drainage, (Figures 10 and 11). The watershed ranges from less than five miles to about forty miles in depth. This narrow band is heavily forested, with small amounts of agriculture on some of the upland areas. Many of the streams and rivers along the south shore wind slowly through nearly level and sometimes marshy terrain. These streams are often turbid, due to the sand and clay substrate which exists in most of this portion of the watershed. Some carry heavy loads of red clay, particularly in the Wisconsin tributaries.

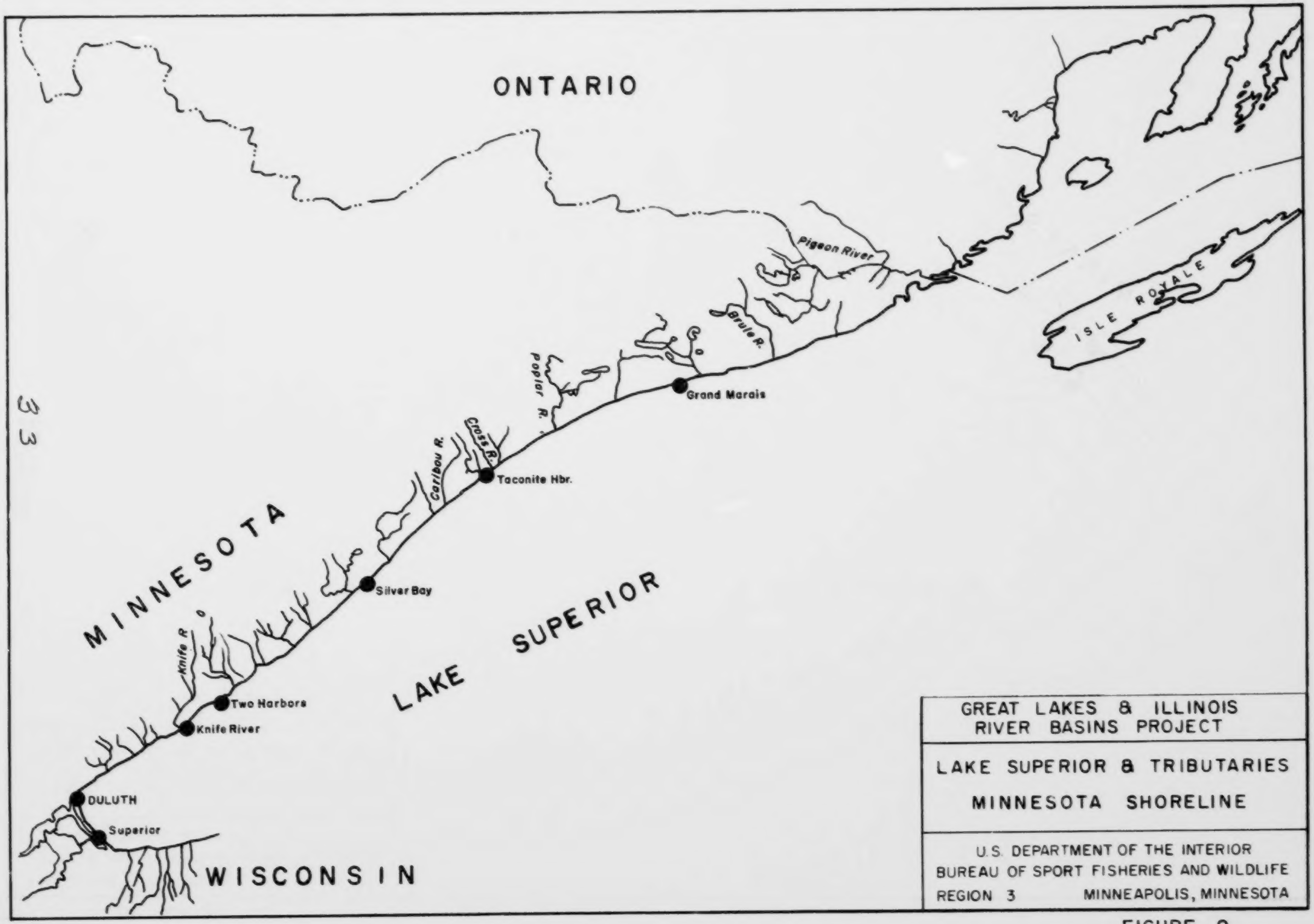

C A N A D A
COOK CO.
LAKE CO.
ST. LOUIS CO.
HUDSON BAY
ST. LOUIS RIVER
WATERSHED DIVIDE
LAKE SUPERIOR
WISCONSIN
Grand Portage
HOLLOW ROCK CREEK
MINERAL CREEK
Hovland
GRAND MARAIS
ROSE BUSH CREEK
BLACK POINT CREEK
SPRUCE CREEK
Lutsen
Schroeder
Little Marais
Beaver Bay
SILVER CREEK
TWO HARBORS
Knife River
Lakewood
Lakeview
DULUTH
West Duluth
SUPERIOR
TEMPERANCE
MANITOU
CARIBOU
BAPTISM
BEAVER
SPLIT ROCK
GOOSEBERRY
STEWART
KNIFE
SUCKER
FRENCH
LESTER
AMITY
T65N
T64N
T63N
T62N
T61N
T60N
T59N
T58N
T57N
T56N
T55N
T54N
T53N
T52N
T51N
T50N
T49N
T48N
R4W
R3W
R5W
R6W
R7W
R8W
R9W
R10W
R12W
R13W
R14W
R15W
R16W
R17W
R4E
R5E
R6E
N
S
E
W
NOTE - NUMBERS WITHIN A WATERSHED AREAS REFER TO AREA IN SQ. MI.

MAP
SHOWING
LAKE SUPERIOR - NORTH SHORE
DRAINAGE AREAS

DEPARTMENT OF CONSERVATION
DIVISION OF GAME & FISH

8-25-42

FIGURE 8

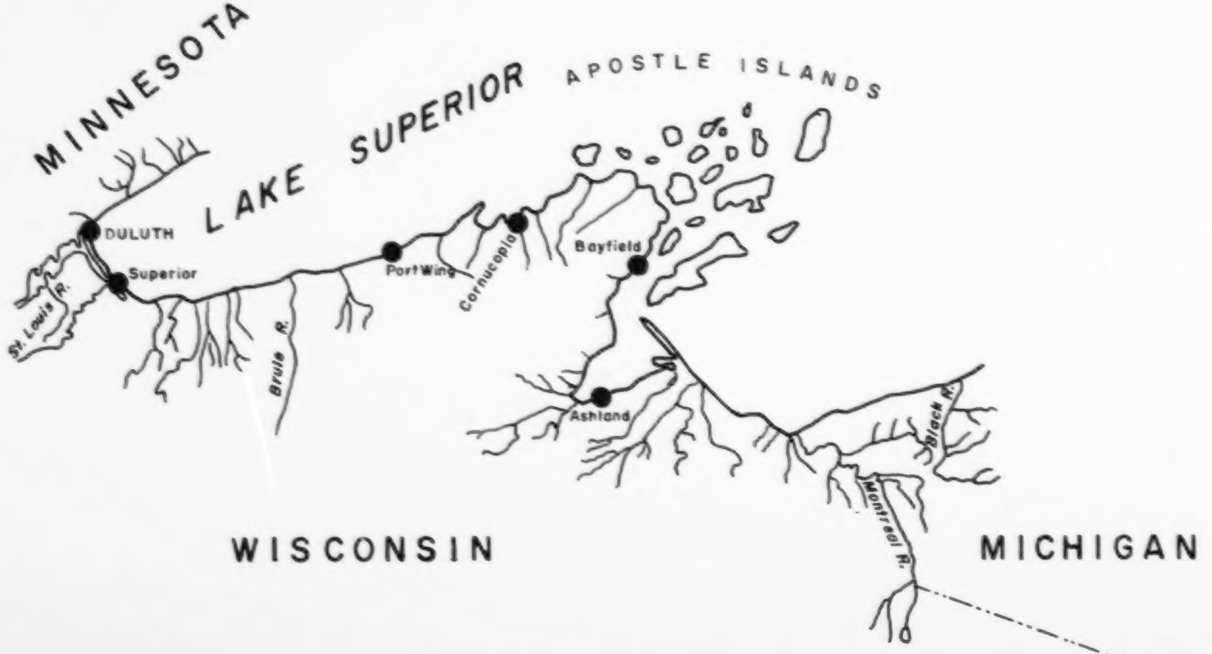

ONTARIO
Pigeon River
ISLE ROYALE
Brule R.
Poplar R.
Grand Marais
Cross R.
Caribou R.
Taconite Hbr.
MINNESOTA
Silver Bay
LAKE SUPERIOR
Knife R.
Two Harbors
Knife River
DULUTH
Superior
WISCONSIN

GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

LAKE SUPERIOR & TRIBUTARIES
MINNESOTA SHORELINE

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF SPORT FISHERIES AND WILDLIFE
REGION 3 MINNEAPOLIS, MINNESOTA

FIGURE 9

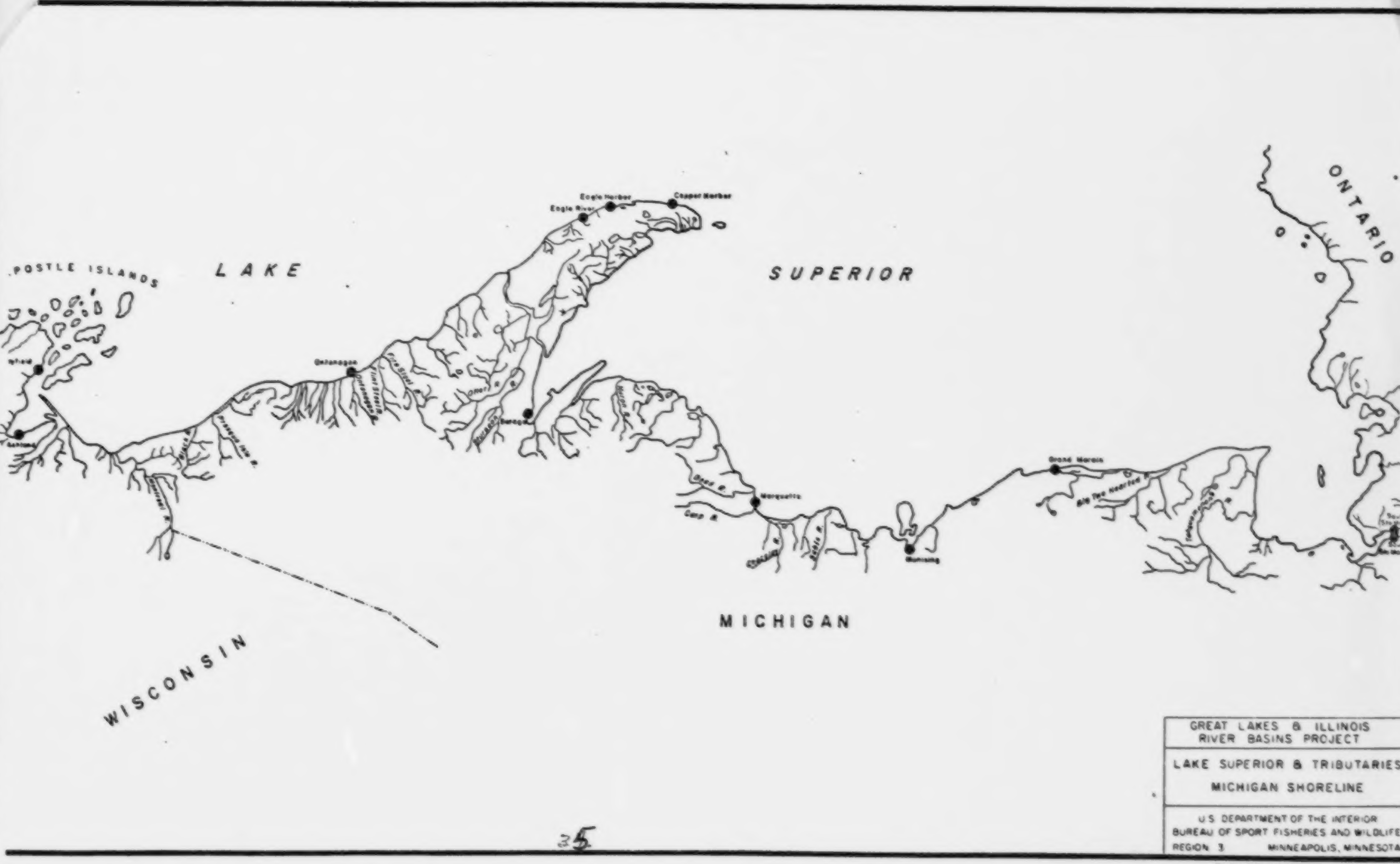

MINNESOTA
LAKE SUPERIOR
APOSTLE ISLANDS
DULUTH
Superior
St. Louis R.
Brule R.
Port Wing
Cornucopia
Bayfield
Ashland
Black R.
Montreal R.
WISCONSIN
MICHIGAN

GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

LAKE SUPERIOR & TRIBUTARIES
WISCONSIN SHORELINE

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF SPORT FISHERIES AND WILDLIFE
REGION 3 MINNEAPOLIS, MINNESOTA

FIGURE 10



.POSTLE ISLANDS
LAKE
SUPERIOR
ONTARIO
Ashland
Eagle River
Eagle Harbor
Copper Harbor
Ontonagon
Presque Isle R.
Montreal R.
Flint Steel R.
Ontonagon R.
Fire Steel R.
Otter R.
Baraga
Huron R.
Dead R.
Marquette
Carp R.
Chocolay R.
Munising
Grand Marais
Big Two Hearted R.
Tahquamenon R.
Sault Ste. Marie
MICHIGAN
WISCONSIN

GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT

LAKE SUPERIOR & TRIBUTARIES
MICHIGAN SHORELINE

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF SPORT FISHERIES AND WILDLIFE
REGION 3 MINNEAPOLIS, MINNESOTA

FIGURE II

FISH AND WILDLIFE RESOURCES

HISTORICAL BACKGROUND

Sport Fisheries.--The importance of sport fishing in the Lake Superior basin has long been recognized. An early reference by R. B. Roosevelt, 1865, told of catching two pound trout "to the heart's content" (Mich. Water Res. Comm., 1967). Another reference to charter boat fishing on Lake Superior gives beginning dates in the mid-1920's (Watson, 1968). This author also refers to private rowboats being used for trolling for lake trout as early as 1899.

This trend in fishing on Lake Superior expanded rapidly through the late 1940's and early 1950's. By this time, however, stocks of most sport fish had declined and sport fishing success had fallen off sharply. The lamprey control program has reversed this trend and sport fish populations are coming back. Private and charter boats are active and fishing in the Apostle Islands area and other sectors of the lake provides some topnotch enjoyment.

The lake trout has been the overall favorite, but walleye, northern pike, and brook trout have also been historically important species which have provided many man-days of sport. Recent introductions of such species as the rainbow and brown trout, smelt, and coho salmon have expanded the variety and abundance of fish available to the sport fisherman.

Information on sport fish harvest in Lake Superior is limited. Fishing intensity, success rates, species composition in the catch, and year to year trends are all subjects for which additional information is needed.

Commercial Fisheries.--The abundant supply of fish in the Great Lakes played an important part in the development of bordering land areas from the beginning of human settlements. Until about 1830, commercial fishing was confined almost exclusively to Indians and to employees of the Hudson Bay and American and Northwest Fur Companies.

There are reports of Indians using gill nets in the Upper Great Lakes as early as 1781. One of the principal reasons for the location of Indian settlements along the Lake Superior shoreline was the availability of fine food fish. The quality of these fish was highly esteemed and early explorers gave repeated and enthusiastic accounts of Lake Superior fish.

Extensive use of fish by early settlers and traders made it apparent that there were possibilities for a commercial fishery. The American Fur Company established the first major commercial fishing venture. During the 1820's and 30's, fishing stations were established on Grand Portage, Isle Royale, at L'Anse, Grand Island, Whitefish Point and at the "Soo".

Most of this fishing was done by gill netting. By its very nature, however, gill netting in the 1800's was a limited venture. All netting was made by hand. Stones fastened by strings were used as weights, and floats were hand-whittled out of 6 to 10 inch cedar splinters, split at one end and pinched onto the float line like a clothespin. All weights and floats were removed each time the nets were brought ashore.

This was a laborious procedure and only a few thousand feet could be set. The nets were either set near shore for whitefish, lake trout, and herring, or carried by rowboat or sailboat to the fishing grounds, which were always within sight of land.

Due to lack of refrigeration, the catch was salted and packed into barrels which were shipped to the growing markets in the Middle West. Some were sent as far as New Orleans.

The Panic of 1837 and high fishery production combined to depress and flood the market for Lake Superior fish. This contributed to the failure of the American Fur Company in 1842, marking the end of the first chapter in Lake Superior's commercial fishing.

Commercial fishing was nearly absent from the lake until the 1850's, when the development of the copper, iron and lumber industries in the Upper Great Lakes region and the rapid growth of midwestern cities created a demand for Lake Superior fish. Major commercial fishing operations started again around 1860 in Whitefish Bay. From here it expanded rapidly westward, supplying fish to the mining towns, lumber camps and other communities which were rapidly developing in the Upper Great Lakes Region.

The Civil War created new market demands and in 1864 the first pound net was set at Whitefish Point to harvest whitefish, the most important species in the commercial catch at that time. By 1870, the fishery could be characterized as a moderately intensive shore fishery, with some activity by larger boats in more distant waters. Commercial fishing was scattered among small ports along the shoreline, with some concentrations in the bay areas. Less than one-half of the lake's waters were fished and the severe winters and short summers further reduced the lake's production.

Around 1875, the trap net was introduced in Lake Ontario. Its use spread rapidly throughout the lakes but it was slow to become established in Lake Superior. The first trap net was probably set in the lake somewhere between 1903 and 1908.

The Canadian fishery did not develop as extensively as did the fishery on the American side and when U. S. production began to decline around 1890, considerable capital was shifted to Canada. This gave the Canadian fishery a temporary boost at the expense of American production. Yet, the U. S. side has never produced less than three-fourths of the lake's total catch.

In 1871, the first steam-driven vessel appeared on the lake and others soon followed. This resulted in some harvesting changes. Prior to 1890, gill nets were lifted by hand. By 1890, some of the steamers were using steam power to lift gill nets over a drum or cylinder. About 1900, the automatic gill net lifter was invented. This allowed the use of more and longer nets. By 1900, the character of the fishery was beginning to change. Lake trout had surpassed whitefish in production, and the lake herring was becoming a major part of the catch. Thus, lake trout, lake herring and whitefish, the three species that were to dominate the lake's production for the next five decades, had become firmly established in the commercial market.

In the 1890's, fishing with baited hooks for trout became popular and remained a fairly important method of harvesting trout in Lake Superior until the decline of lake trout in the 1950's.

Until 1930, gill nets were made from linen, but about this time the softer, more elastic cotton thread began to replace linen in most fisheries. Cotton continued to be used until the nylon gill nets became available in the late 1940's.

The nylon gill net represents a major advance in commercial fishing. Studies by Pycha (1962) indicate that nylon nets are 2.25 times more effective than cotton nets for taking legal-sized lake trout, while according to McCombie and Fry (1960) nylon nets are 2.9 times as effective as cotton nets for taking whitefish. In addition, the nylon nets have greatly reduced maintenance. Conversion to large mesh nylon gill nets took place in Lake Superior from 1949 to 1952, principally in 1950 and 1951.

For the fisherman who can afford them, there are many devices available today that can improve his chances of success.

Fathometers and automatic pilots assist in locating suitable grounds and reduce the need for manpower. With radar, the fisherman can find his net buoys in fog or snow as far as 60 miles from shore with uncanny ability; in addition, many of the hazards associated with lake navigation are considerably reduced.

Declines in the lake trout, whitefish and lake herring populations resulted in experimentation with trawlers to harvest previously underutilized species. However, trawling operations in Lake Superior are extremely limited. Table 4 summarizes total Great Lakes commercial fishery landings and values by decade, from 1920 to 1966.

The historical importance of the Great Lakes for commercial fishing has declined, while the value of recreational fishing has increased. This does not diminish the value of commercial fishing, but demonstrates the ever-increasing importance of sport fishing, hunting and other related forms of recreation which have been drawn to the Great Lakes area.

In recent years, the commercial fishing industry in the Great Lakes Region has been beset with many problems, among them being drastic declines in abundance of the choicer species. After a sharp increase in the value of the catch in the decade 1940-49, a leveling-off took place during the 1950's, with severe drops in the early 1960's (Table 4). Total Great Lakes commercial production has remained essentially unchanged at a little more than 100 million pounds annually.

Table 4.--Average Commercial Landings and Value of Fish From the Great Lakes, United States and Canada, combined.

Years	Landings (Millions of Pounds)	Value (Millions of Dollars)*
1920-1929	106.2	8.8
1930-1939	111.7	7.6
1940-1949	101.1	14.9
1950-1959	111.3	15.6
1960	104.5	10.8
1961	113.4	11.4
1962	116.4	9.5
1963	99.6	9.3
1964	88.6	9.5
1965	98.8	10.8
1966	115.6	10.3

*Dollar values uncorrected for general price level increases caused by inflation.

FISH

Traditionally, Lake Superior has furnished around 16 percent of the total Great Lakes commercial fishery production. In terms of pounds per acre it is the least productive of the Great Lakes. Most of the fishing is done in the United States waters, with Canadian production seldom exceeding 5 million pounds.

The lake is dominated by salmonids. Over the years, lake trout, whitefish, and lake herring have been the three most important species in the commercial catch. Lake Superior has not experienced the major species change to the extent that has occurred in the other Great Lakes. However, the fishery base has undergone some significant changes. Under the combined effects of the sea lamprey predation and increased fishing pressure following the lamprey invasion in the 1940's, the lake trout population collapsed in the late 1950's. Subsequent shifts of fishing efforts to lake herring and chubs, following this collapse, have produced changes in these stocks also.

In addition to the sea lamprey, the alewife and smelt have also established themselves in Lake Superior. The smelt is now the most abundant inshore fish in the lake and is harvested extensively by both the commercial and sport fisherman, while the alewife population has remained at a low level.

Sport fishing on Lake Superior and the many tributaries and inland lakes, provides high quality recreation for thousands of fishermen. Productivity of these waters is generally very low, but is compensated for by the scenic beauty of the area and the highly prized species of trout which are available.

Overall, the lake trout has been, and continues to be, the most important sport fish caught in Lake Superior. Lake-run brown trout and rainbow trout receive heavy use during early spring, but the lake trout attracts the most hook and line fishermen. The native brook trout, plus recently introduced coho and chinook salmon, are the other salmonids available to the fisherman. Northern pike, walleye and yellow perch are other important sport fish utilized in Lake Superior and its tributaries and inland lakes. The abundance of these fish varies seasonally and from area to area, but due to several limiting factors, many populations are under-harvested. Those species of fish commonly caught in Lake Superior and its watershed are listed in Table 5.

With 81 percent of Lake Superior deeper than 120 feet, (Figure 3) most sport fish populations are restricted to the bays and shoal areas. This makes such areas as Whitefish Bay, Keweenaw Bay, and the Apostle Islands exceptionally good sport fishing areas.

Waterfalls or other natural obstructions occur near the mouths of many Lake Superior tributaries, preventing upstream migration.

Table 5.--Common Sport Fish of the Lake Superior Basin

Common Name	Scientific Name
Lake whitefish	*Coregonus clupeaformis* (Mitchill)
Coho salmon	*Oncorhynchus kisutch* (Walbaum)
Round whitefish	*Prosopium cylindraceum* (Pallas)
Rainbow trout	*Salmo gairdneri* Richardson
Brown trout	*Salmo trutta* Linnaeus
Brook trout	*Salvelinus fontinalis* (Mitchill)
Lake trout	*Salvelinus namaycush* (Walbaum)
Smelt	*Osmerus mordax* (Mitchill)
Northern pike	*Esox lucius* Linnaeus
Muskellunge	*Esox masquinongy* Mitchill
White sucker	*Catostomus commersoni* (Lacepede)
Northern redhorse	*Moxostoma macrolepidotum* (LeSueur)
Black bullhead	*Ictalurus melas* (Rafinesque)
Channel catfish	*Ictalurus punctatus* (Rafinesque)
Yellow bullhead	*Ictalurus natalis* (LeSueur)
Rock bass	*Ambloplites rupestris* (Rafinesque)
Bluegill	*Lepomis macrochirus* Rafinesque
Smallmouth bass	*Micropterus dolomieui* Lacepede
Largemouth bass	*Micropterus salmoides* (Lacepede)
White crappie	*Pomoxis annularis* (Rafinesque)
Black crappie	*Pomoxis nigromaculatus* (LeSueur)
Yellow perch	*Perca flavescens* (Mitchill)
Walleye	*Stizostedion vitreum vitreum* (Mitchill)

Until fish were planted above these obstructions, very few of these streams had sport fish populations. The transplanting activities brought in many exotics, but only a few, such as the rainbow trout, brown trout, and certain warmwater species were successful. The range of the native brook trout was greatly expanded and these fish, together with the exotics, produced a much improved fishery, both in quantity and quality.

The remainder of this section is devoted to a discussion of the important sport and commercial fishes of Lake Superior.

Lake Trout.--Late in the 19th Century, lake trout fishing for sport became very popular. Fishing from rowboats was the earliest method, but this virtually restricted the sport to inshore waters. Trolling from larger and safer boats later became popular, making more areas of the lake accessible to fishermen. Near the end of this early period, these larger craft were hired out to summer visitors and party fishing quickly became a popular sport (Watson, 1968). Until hit by drastic population declines, the lake trout was one of the more important species in both the sport and commercial catch. Its value was high, both in quality and quantity.

There are at least three types or races of this species in the lake. The common or "lean" trout (Salvelinus n. namaycush) is the principal inhabitant of inshore areas. The "fat" trout or siscowet

(Salvelinus n. siscowet), is the principal occupant of the deeper waters (and at one time probably inhabited the deeper waters of the other Great Lakes.) The "humpers" occur more locally in certain offshore areas (Hubbs & Lagler, 1958; Rahrer, 1967).

As the commercial fishing industry developed in Lake Superior during the latter part of the 19th Century, lake trout increased in importance and by 1897 it was the leading producer, in terms of poundage. It maintained this position until it was eclipsed by the lake herring in 1903. In terms of value, however, lake trout continued to be the top producer, accounting for 50 to 60 percent or more of the total value of the Lake Superior commercial catch up through 1949. The largest harvest of lake trout in U. S. waters occurred in 1903, when 5.6 million pounds were taken. Following this, production leveled off between two and three million pounds annually and remained at this level for the next fifty years (Table 6). During this latter period, there was a westward shift in the major trout production centers.

Table 6.--Lake Trout Commercial Production in U. S. Waters for Lake Superior for Selected Periods

Period	Average Annual Production in Pounds
1879	1,465,000
1885-1892	3,416,000
1893-1907	4,599,000
1908-1925	2,165,000
1926-1949	3,049,000
1950-1955	2,722,000
1956-1960	1,219,000

During the 1940's, the lake trout populations collapsed in Lakes Huron and Michigan and the sea lamprey began to increase in abundance in Lake Superior. Strong demands for lake trout and a limited supply resulted in a ready market. With Lake Superior the only one of the Great Lakes still possessing a lake trout population, some gear was moved to Lake Superior from the lower lakes.

Introduction of the nylon gill nets occurred in the late 1940's. Between 1949 and 1952 most large-mesh gill nets were converted to nylon. These new nets were 2.25 times as effective as cotton nets had been for taking lake trout (Pycha, 1962). These changes resulted in additional pressures on the lake trout.

The catch of lake trout remained fairly constant until 1954, but by 1949 there was already evidence that the stocks were declining. In 1949, trout production was up 6 percent above the 1929-1943 mean in State of Michigan waters of Lake Superior, but the commercial fishing pressure was up 62 percent (Hile, 1953). During the late 1940's and early 1950's, the combination of the efficient nylon gill net and increased fishing pressure on the lamprey-depleted stocks maintained the commercial catch at a fairly stable level. By 1955, this combined pressure was reflected in the commercial catch, which dropped from 3.1 million pounds in 1951 to 2.1 million pounds in 1955. Both the lamprey predation and the fishing pressure were applied most to the inshore stocks and by 1959 natural reproduction of the lean variety lake trout had virtually ceased in the inshore waters of Lake Superior. Only 380,000 pounds of lake trout were taken commercially in 1960.

Charter boat fishing for lake trout by sport fishermen had reached its high before 1955. An estimated 175 charter boats were active in 1950, the record high year. Shortly after this, however, the collapse of the lake trout populations occurred. With them went the charter boats. By the early 1960's only nine remained (Watson, 1968). Those factors that were decimating the lake trout were also causing depletion of other sport fish populations, with the exception of the smelt.

From 1959 until 1964 there was no recorded natural reproduction of "lean" lake trout in the lake. By 1960, the stocks were at an extremely low level. Meanwhile, lamprey control measures had been concentrated on Lake Superior in an attempt to save some of the natural stocks. Planting of hatchery reared trout had been started in 1952 and massive plantings were begun in 1958.

The limited fish populations in the early 1960's resulted in low numbers of sport fishermen using or maintaining boats on Lake Superior. With lamprey control efforts, restrictions on commercial fishing, and extensive stocking programs, the lake trout and most other sport fish populations are making a comeback.

This, plus popularity of the recently established coho salmon, has resulted in an expansion of the number of charter boats from the low of 1960, to an estimated fifty now operating. This number is increasing rapidly each year, due to improved fish populations, including coho salmon, and the tremendous publicity that this type of fishing is receiving.

1961 was a peak year for the lamprey, but by 1962 control measures were well along. The lake trout fishery was closed that same year, except for limited fishing to monitor stocks. This monitoring was done by fishermen with permits or under contract with the States.

During the past few years, the lake trout population in Lake Superior has nearly increased to pre-lamprey levels in numbers, but not in condition. Lake trout are slow growing and slow to mature. It requires 6 years for males to reach sexual maturity and a length of 25 inches. Females require about 7 years to become sexually mature and generally their full reproductive capacity is not reached until their eighth year. Thus, trout from the first major stockings in 1958 did not spawn in significant numbers before 1964. Even this was limited, as the fish had been susceptible to predation during the peak years of lamprey abundance and only a few had survived to spawn. However, in 1965 a Bureau of Commercial Fisheries research vessel captured 80 young-of-the-year trout, indicating that some spawning had occurred. Presently, the extent of the natural production is small, but appears to be improving. In 1967, spawning occurred in the lake and young-of-the-year of naturally produced trout were taken for the fourth consecutive year in experimental nets fished in Wisconsin waters. Hatchery fish still dominate the catches in inshore waters, indicating that recruitment of naturally spawned trout in these areas is still meager. However, siscowets or "fat" lake trout are considerably more abundant. They appear in offshore waters and consist largely of native fish. It will likely require several years before there will be any significant natural reproduction in the lake, and even this will require intensification of the present level of lamprey control.

Whitefish.--The whitefish (Coregonus clupeaformis) is the largest coregonid in the Great Lakes and has been an important species in the Lake Superior commercial catch. There are five known stocks of whitefish along the southern shore of the lake. These stocks exhibit various differences, including an important one of differential growth rates. Whitefish at the eastern end of the lake reach 17 inches (legal size) during their third year. In Wisconsin, they require 7 years, while whitefish in Munising Bay have not reached legal size after 17 years. In addition, "Little or no correlation exists between annual fluctuations in production of whitefish in U. S. and Ontario waters. The lack of correlation suggests that U. S. and Canadian fishermen are exploiting different stocks and that conditions controlling fluctuations of the take are not the same over the entire lake." (Dryer, 1963).

As in the other Great Lakes, the whitefish was the principal species sought in the early years of the Lake Superior commercial fishery. Until the 1890's, whitefish constituted the most important species in the lake's catch before yielding first place to lake trout. Whitefish stocks have been heavily fished, first by haul seines and later by gill nets and pound nets. The first pound net in Lake Superior was established for whitefish at Whitefish Point in 1864. By 1885 there were 125 pound nets being fished in the Apostle Island region alone.

Under heavy fishing pressure all stocks along the southern shore declined to where they were unable to maintain high production. In 1885, commercial production of whitefish in the United States waters of Lake Superior was near 4.5 million pounds; 1893 was the last year with production above two million pounds. The 1903 level of production, which was above one million pounds, did not occur again until 1948. In 1926, Koelz pessimistically stated that from a commercial point of view the whitefish was practically extinct along the southern shore of Lake Superior. He based this on the 1922 catch of 319,000 pounds. The following year, production dropped to an even lower 144,000 pounds and continued to remain low for the rest of the decade. Despite this reduced production, whitefish were able to maintain third position in the commercial fishery behind lake herring and lake trout.

During the 1930's and 1940's the stocks were not fished very heavily. Production ranged between 200,000 and 400,000 pounds. Whitefish production jumped above one million pounds in 1948 and remained at this level for the next two years. This increase in production was probably due to one or more strong year classes. In 1951, production dropped to 442,000 pounds. During the same period the progressive decline of lake trout made the high-priced whitefish even more valuable and greater pressures were applied. In 1954 and 1955, production was again above one million pounds. This was probably due to two good year classes. The following years witnessed a progressive decline to 284,000 pounds in 1960. Heavy fishing has continued and the present production level of 300,000 to 400,000 pounds annually appears to represent the maximum return that can be expected from the stocks.

Rainbow Trout.--The rainbow trout (Salmo gairdnerii Richardson) in the Lake Superior Basin is the result of the mixing of several introduced stocks. They were first stocked in Lake Superior in the late 1800's and have since developed into an important sport fish. Rainbows are generally associated with the shoal areas of the lake, and with the larger tributaries which they ascend during their early spring spawning runs.

The rainbow is utilized primarily as a sport fish, taken in the larger tributaries. The small amount of available spawning habitat on many tributaries concentrates the fishing effort to over 1,000 man-hours annually per stream mile on many streams. This fishing density is common on many tributaries along the U. S. shore.

The lamprey buildup was destructive to rainbow populations. However, stocking programs, anadromous characteristics of the rainbow, and differential growth and maturation rates kept the rainbow trout populations from falling to the low levels of the lake trout.

Fishing for rainbow trout from large chartered boats has developed along with the fishery for lake trout in recent years. This has occurred because of improving populations of both species of fish.

Lake Herring.--The lake herring (Coregonus artedi, LeSueur) occurs in all of the Great Lakes and in the deeper inland waters of the St. Lawrence, Hudson, and Mississippi River drainages. In Lake Superior, as in the other Great Lakes, it has played an important role in the commercial fishery. In addition to providing forage for lake trout and other large predators, it has held first position in the lake's commercial catch since 1903.

Until the 1890's, lake herring were caught chiefly for local consumption. As demand outside of the immediate vicinity grew, production increased rapidly. By 1899, it exceeded one million pounds for the first time. By 1903, herring production had jumped to over six million pounds. It continued on a general upward trend throughout the next 30 years, generally making up one-half or more of the total Lake Superior catch. Production was variable but most of the fluctuations probably reflected weather conditions during October-December, the peak harvest season, with resultant variations in fishing pressure, rather than any major changes in the stocks themselves. Though the catch reached 17 million pounds in 1941, there is little evidence to indicate that this resulted in any major changes in the stocks. By the end of the 1940's and early 1950's, however, there were indications of declines and changes. Much of the decline can be traced to the near collapse of the herring fishery in the Duluth area. The average catch per unit of effort at Duluth in 1951-53 was over 300 pounds. In 1960 it was only 68.5 pounds. There was additional evidence of a decline in Michigan waters (Dryer, 1964).

Between 1951 and 1961, herring production varied only slightly between 10 and 12 million pounds, yet the stocks were undergoing changes. The average size of the lake herring captured between 1956 and 1961 was greater than that of herring taken between 1951 and 1955, and the average weight per fish approximately doubled from 1954 to 1964. Thus, with the same poundage being removed from the lake, the number of fish removed was decreasing. The number of fish represented by the catch data indicates that the true herring abundance during the 1963-1966 period was approximately 23 percent in Michigan waters and 17 percent in Wisconsin waters of what it was in the 1954-1956 period.

It is difficult to accurately assess the condition of the herring stocks during the 1950's. Comparisons with past commercial catches and catch per unit effort figures cannot be made because of the conversion to nylon gill nets in the herring fishery during this period. Unlike conditions in the large-mesh gill net fishery, small-mesh herring nets were slowly converted to nylon during a 5-10 year period and it is impossible to make adjustments in the statistics for the effects of these nets. It is quite possible that fishing intensity may have been underestimated and the abundance of herring overestimated during the 1950's (Dryer, 1964).

Traditionally, the fourth quarter of the year (October-December) has been considered the peak season for herring fishing, and spawning runs during this time have produced large catches. Between 1929 and 1961, 90 percent of the herring catch was taken by small-mesh gill nets during the last quarter of each year. In 1962, almost 75 percent of the herring landed were taken during the final quarter of the year. In 1963, the percentage dropped to slightly over 60 percent and in 1964 declined even further to almost 40 percent (Figure 12).

Corresponding with the recent drop in peak season production, the annual catch of herring has declined considerably from 11.4 million pounds in 1962 to 9.9 million the following year. This decline continued over the next four years, reaching a modern-era low of 4.5 million pounds in 1966.

The catch per thousand feet of net declined sharply from 523 pounds in 1954 to 179 pounds in 1964 (Figure 13). The decline in yield per unit of input may not be surprising when the changing species composition on the lake is considered. For example, when the abundance of lake trout and whitefish was high, fishing for species such as herring and chub was limited. These species, especially herring, were generally harvested only during periods when availability was good; thus, the yield per unit of effort was high. However, as the higher valued species gradually disappeared from the lake, it was necessary for the fishermen to exert effort not only during periods of high yield, but also during periods of low yield. Because of this decline in the herring population and because exploratory bottom trawling conducted by the Bureau of Commercial Fisheries for herring was not successful, it seems doubtful that an increased catch of herring can be expected in the near future. The reasons for the herring decline are not clearly understood but there are indications that increased competition from smelt has lowered the success of herring reproduction and growth and that the herring population has not been able to withstand the additional fishing pressures.

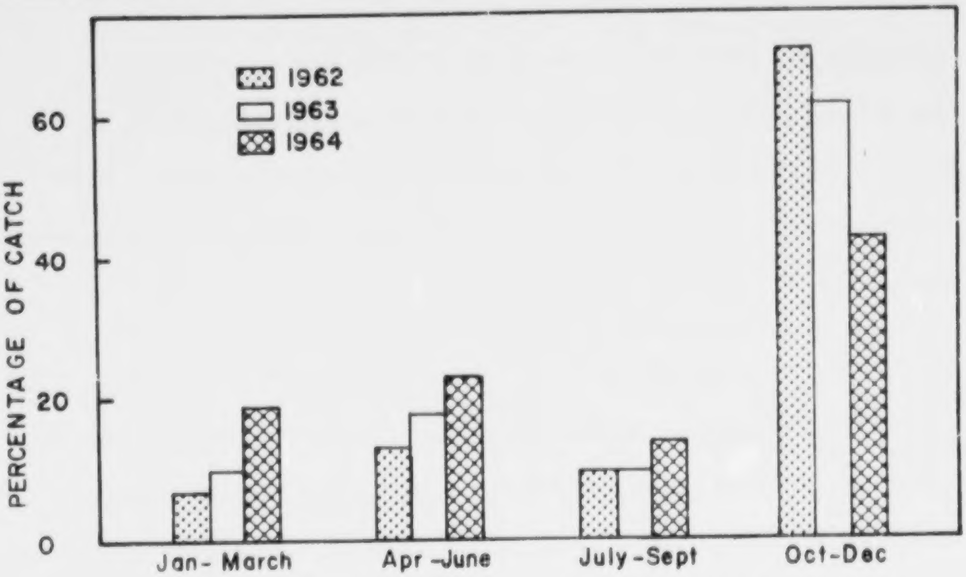


Figure 12 - Relative Catch of Lake Herring from Lake Superior by Quarter, 1962-1964

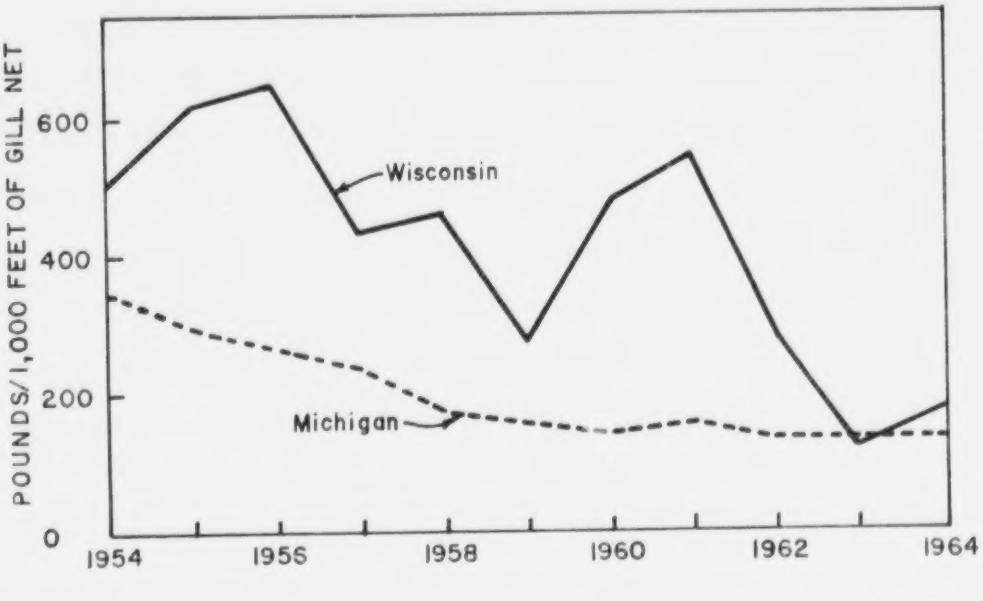


Figure 13 - Catch of Lake Herring per Unit of Effective Effort, 1954-1964

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LAKE SUPERIOR & TRIBUTARIES

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF SPORT FISHERIES AND WILDLIFE
REGION 3 MINNEAPOLIS, MINNESOTA

Chubs.--The chubs are the deep water members of an extremely complex sub-genus (Leucichthys), five species of which are found in Lake Superior. The bloater (Coregonus hoyi) is the most common of the five. The others are the blackfin cisco (C. nigripinnis), shortjaw cisco (C. zenithicus), shortnose cisco (C. reighardi) and kiyi (C. kiyi). Until recently the chubs played a minor role in the commercial fishery and they have made no direct contribution to the sport fishery. With the decline of the lake trout stocks, however, fishermen were forced to turn to other species. Like the whitefish and herring, the chubs became increasingly important in the commercial catch of Lake Superior. Their relative importance in the commercial catch increased with the decline of lake herring production in the 1960's.

Until 1940, figures on chubs and herring were combined. Between 1940 and 1957 chub production was generally under 500,000 pounds annually. Production exceeded one million pounds in 1958 for the first time and has remained above 1 million pounds since then.

The coregonids are an unstable group and the changes within the total population structure as well as growth changes in the bloaters specifically indicate that the population is under stress. Since most of these changes began prior to the increased commercial fishery in 1957, indications are that, while fishing pressure was probably a factor in the case of the blackfin cisco, it was not the controlling factor in the changes in the coregonid group as a whole.

The traditional gill net fishery of Lake Superior took only the larger chubs and by 1930 the blackfin cisco had been reduced to low levels by a selective fishery. Some biologists have stated that due to the genetic plasticity of the chubs, the blackfin was absorbed into the gene pool through interbreeding with more common species and today this species is considered rare.

There is strong evidence to indicate other changes have also been occurring in the chub stocks over the past 40 years. During the 1930's the shortjaw cisco was the only large chub common enough to support a commercial fishery in Lake Superior. Koelz (1926) indicated that the shortjaw ranked second in abundance only to the lake herring. Between 1958-1965 the shortjaw comprised only 8 percent of the chubs taken by the Bureau of Commercial Fisheries research vessel Siscowet in the Apostle Island region, while the bloater yielded 92 percent of the take.

Studies have shown the commercial chub catch of Lake Superior to be composed of 90 percent bloaters, eight percent shortjaw cisco and two percent kiyi. The bloater is a deep-water species, found within a 10-90 fathom range and most abundant at depths of 30-60 fathoms. It is the slowest growing and smallest of the chubs. Recent studies, however, have indicated that the growth characteristics of the bloater have changed and along with an increase in abundance there has also been an increase in average size. Between 1951 and 1964 there were steady increases in average lengths and weights of bloaters taken in the Apostle Islands region. The percent of these fish longer than 8.9 inches increased from 45 percent in 1959 to 99 percent in 1965. Calculated lengths were higher in the 1962-1965 period than they were between 1958 and 1961. This increase in average length was accompanied by an average increase in weight and an average increase in growth rates (BCF, 1968).

"No explanation can be offered for the improved growth of bloaters in recent years. Such factors as meteorological conditions, fluctuations in lake levels, changes in basic productivity and chemical characteristics of the lake, and changes in fish populations have been considered, but no evidence has been found that any one of these factors is responsible for the striking improvement in growth of bloaters." (BCF, 1968).

Similar changes have taken place in Lakes Huron and Michigan. In Lake Huron the chub population collapsed in 1966 and there are indications of an imminent collapse in Lake Michigan. It is not known whether the chub population in Lake Superior will follow the same pattern or not.

Presently the production of chubs from Lake Superior is limited by a weak market. Studies by the Bureau of Commercial Fisheries indicate that production could be increased and a sustained yield could be maintained on the basis of the stocks as they exist now. However, this would require trawl fishery utilization of the bloater, which cannot be effectively taken by the gill net.

Due to the potential instability of the chub population as well as the possibility of incidental catches of smaller lake trout, management agencies are reluctant to encourage fishermen to invest in the fishing gear and market development necessary to support such a fishery.

Smelt.--Smelt (*Osmerus mordax*) were successfully introduced into the Lake Michigan drainage basin in the 1920's and were first discovered in Lake Superior in 1930. Little is known about the condition of the stocks during the next 20 years, though some were taken in the commercial catch and sport fishermen seined them during the spring spawning runs.

The smelt population began to build up during the late 1940's, when with the decline of the lake trout and other large predators, conditions were probably enhanced for this species. In addition to reduced predation, there was reduced competition from juvenile lake trout and lake herring for food and space. These conditions enabled the smelt population to increase rapidly through the 1950's and by 1960 smelt were probably the most common inshore species in the lake.

Sport fishing for smelt has assumed carnival-like proportions in recent years. Smelt dipping provides the most popular early spring fishing along the mouths of numerous streams entering Lake Superior. The spawning runs are heaviest at night and thousands of fishermen stand shoulder-to-shoulder in many streams dipping or seining the silvery smelt. The Duluth-Superior area is a staging point for many of these fishermen and Minnesota's North Shore highway is virtually jammed for miles during the height of the smelt runs.

Commercial smelt production has averaged over one million pounds a year from 1961 to 1966. Most of the catch is taken in Minnesota by a very few boats in only a few weeks of fishing as the smelt migrate into shore for spawning. In addition to the Minnesota waters now being fished, exploratory cruises by the Bureau of Commercial Fisheries have found good concentrations in or near Whitefish Bay, Shelter Bay, and Keweenaw Bay. There is some evidence to suggest that the habits of certain lake trout stocks may be changing to conform with the seasonal distribution of smelt, and that the habits of lake herring may likewise be affected by concentrations of smelt in certain areas.

Sturgeon.--The sturgeon (Acipenser fulvescens) was once abundant throughout the Great Lakes, reaching its greatest abundance in Lake Erie. Sturgeon were least abundant in Lake Superior (Hubbs and Lagler, 1958). The sturgeon population began to decline soon after the commercial fishery started on Lake Superior. They were considered a nuisance of little value that often caused considerable damage to nets. At first they were heavily fished, in order to remove them from the fishing grounds. Many were placed on the beach to rot. Under these pressures, the slow-growing late-maturing sturgeon was reduced to near extinction levels.

In 1929, all fishing for sturgeon was prohibited in Lake Superior and under this protection they have made some recovery, although this sturgeon is still classified as an endangered species.

Salmon.--The State of Michigan planted 192,000 coho salmon (*Oncorhynchus kisutch*) smolts in the Big Huron River in 1966. The plantings in 1967 were 467,000 coho and 33,500 chinook salmon (*O. tshawytscha*). The success of this program was not as spectacular as it has been in Lake Michigan. According to the Great Lakes Fishery Commission there was a return of 16 percent the first year, or one-half of what it had been in Lake Michigan. The 16 percent return compares very favorably with the 5 to 10 percent return for the same fish on the West Coast. In addition, a reduced growth rate and total growth may reflect the limitations imposed by limited food and colder water. The 1968 plants were reduced to 375,000 coho and 50,000 chinook. There were also 115,000 coho planted in Minnesota waters in 1969. Future plans for coho involve continuing plants from Michigan and Minnesota, plus possible plantings by Wisconsin. Sport fishing for coho has become an important adjunct to lake trout and rainbow trout fishing. During some periods the coho is the most abundant species taken by sport fishermen.

Other.--Several other species of fish are available to both sport and commercial fishermen who fish either in Lake Superior or other watershed areas. Walleye, yellow perch, and suckers are caught by both sport and commercial fishermen. Northern pike, muskellunge, largemouth and smallmouth bass, brown trout and brook trout, are additional attractions to the sport fisherman. They provide good to excellent fishing during most of the year and attract thousands of tourists to the area.

WILDLIFE

The wildlife resources throughout the basin provide many hunters, photographers, and wildlife observers with high quality recreation. A wide variety of game is available, but the most important game animal throughout the basin is the whitetail deer. Deer populations are very high and some portions of the basin now have insufficient browse to properly winter the herds. Ruffed grouse are second to deer in importance and are as widely distributed. Spruce grouse occur in northern portions of the basin. They were recently placed on the Minnesota game bird list.

The basin's virgin forests of presettlement-time supported relatively small populations of game, in comparison with today. Drastic changes followed settlement. Logging operations and agricultural activities resulted in numerous openings, with an increased abundance of food and habitat for many forms of wildlife. More recent changes, however, in the form of urban expansion and the human population explosion, are having a negative effect on wildlife. Disappearing habitat from natural forest succession and human encroachment, together with insecticides and pollution, are some of the factors responsible.

In addition to deer and grouse, numerous other species, including bear, snowshoe hare, woodcock, and several species of ducks and geese are hunted in the basin. Beaver, mink, muskrats and weasels are fairly common and are important fur animals. Many other species of wildlife are either not abundant enough to attract the hunter or are non-game species. These include: moose, wolf, coyote, red fox, fisher, marten, otter, innumerable songbirds and many others. Most of these are important esthetic species. Moose are increasing in Minnesota portions of the basin and will likely be hunted in the near future, on a permit basis. The timber wolf is present in the basin, but in severely limited numbers in most of its former range. It is classified as an endangered species throughout most of the Lake Superior Basin, although it appears to be holding its own in Minnesota. Isle Royale has well established populations of moose and timber wolves.

Waterfowl use consists primarily of diving ducks. Greater scaup, lesser scaup, ringnecks, American goldeneyes, and American and Red-breasted mergansers are abundant and great numbers of divers raft up on Lake Superior. Occasionally, other diving duck species concentrate in Lake Superior's bays and some of the larger basin lakes. These include the bufflehead and Old-squaw. In addition to the diving ducks, important numbers of "puddle ducks" use the basin's rivers and lakes during breeding or migration periods. These include mallards, black ducks, wood ducks, blue-winged teal and shovelers. Several species of geese migrate through the basin and Canada geese nest in the basin. Loons are common throughout most of the basin. Their beauty and eerie cry add considerably to the wilderness appeal of this area.

FISHERY MANAGEMENT BASE

General.--Habitat and fish stocks alone are not a guarantee of efficient sustained fishery yield. To obtain this objective, sound management of the resource is required. Management of the Great Lakes fishery resources is legally a function of the States. However, the Fish and Wildlife Service also has definite statutory obligations for work on the Great Lakes, with its primary responsibility in the areas of research and technical assistance.

Fishery management programs on Lake Superior are based on cooperative and complementary type projects. Some of the more important programs being carried on are: (1) sea lamprey control, administered by the Great Lakes Fishery Commission; (2) State Aid programs, including the Anadromous Fish Act, the Commercial Research and Development Act, and the Federal Aid in Sport Fish Restoration Act; (3) lake trout rehabilitation, a cooperative program of Federal, State and Canadian agencies since 1958; and (4) salmon and trout plantings by several States. These programs, together with various state programs, provide the basis of fishery management in Lake Superior.

In the past, research has been fragmented among many agencies including State and provincial groups, the U. S. Fish and Wildlife

Service, and individual university research staffs. This has often tended towards piecemeal approaches. Recently a trend towards better coordination and integration of management and research programs has been gradually developing. In 1955, the Great Lakes Fishery Commission was established by treaty between the United States and Canada. The Commission is charged with implementing a program for sea lamprey control and coordination of the fishery research of various agencies. Establishment of a Lake Superior Committee within the Commission framework provides a mechanism for consideration of problems specific to that lake. Some of the fishery management programs carried out through the Commission, as well as programs conducted by various agencies, are described below.

Sea Lamprey Control Program.--In 1958, the Great Lakes Fishery Commission, contracting through the Bureau of Commercial Fisheries, initiated a sea lamprey control program in the U. S. waters of Lake Superior, using a toxicant that selectively destroys sea lamprey larvae in tributary streams. This program has reduced the sea lamprey population from an all-time high in 1961 to 10 percent of this level the following year. The lamprey population remained near the 10 percent level until 1965, when it dropped to 7 percent. In 1968 it returned to near the 1962-1965 level. Though the population dynamics of the sea lamprey are not fully understood, apparently intensification of the control program and an increase in research and monitoring are necessary to keep the problem within workable bounds.

Anadromous Fish Program.--With ultimate control of lampreys to a fraction of their high of the early 1960's, other programs such as the Anadromous Fish Act of 1965 can progress. The work in Minnesota has been aimed at the rainbow trout spawning runs along the North Shore of Lake Superior. There are spawning runs on 56 of the streams along the North Shore, with an aggregate total of 76 miles of stream available for spawning. By means of various types of fishways, either natural or artificial, an estimated 170 additional miles of high quality spawning and rearing habitat will be opened on 16 of these streams. Long-range plans in Michigan call for elimination of 58 barriers to fish migration which will open more than 2,000 miles of stream to angling and spawning for anadromous species.

Stocking of Hatchery-Reared Fish.--Before the 1930's, millions of lake trout fry were planted annually in the upper Great Lakes. Fry stocking was gradually abandoned during the 1930's because the practice appeared to be ineffective. The reduction of lake trout in the 1940's and 50's, however, forced reconsideration of stocking as a method of maintaining abundance or of re-establishing populations. Because potential sources of lake trout eggs were largely limited to inland lakes which were either too small or too remote, stocking of millions of fry was no longer considered feasible. Therefore, attention was directed to rearing lake trout to sizes or ages where chances of survival might be better. A series of experimental plantings in the Great Lakes was begun in 1944 which resulted in the decision to plant yearling lake trout. Although modest numbers of fin-clipped lake trout, mainly yearlings, have been planted in Lake Superior since 1952, intensive annual plantings were not carried out in the lake until 1958. Plantings since then total 17.2 million fish in the United States waters. The purpose of these plantings is to restore a self-sustaining population of lake trout.

Several agencies are cooperatively engaged in some phase of the lake trout program and their efforts coordinated by the Lake Superior Committee of the Great Lakes Fishery Commission. The States of Michigan and Wisconsin share the responsibility of maintaining sources for providing lake trout eggs, which until now have come exclusively from brood fish maintained in hatcheries. Agencies sharing in the hatching, rearing, and distribution of lake trout are the U. S. Bureau of Sport Fisheries and Wildlife and the States of Wisconsin and Minnesota.

The stocking program also involves smaller annual plantings of other salmonids. The State of Michigan has planted coho and chinook salmon on an experimental basis, with coho plantings totaling 192,000 in 1966; 467,000 in 1967; and 373,500 in 1968; and chinook, totaling 33,500 in 1967 and 50,000 in 1968. Minnesota planted 115,000 coho smolts in the Pigeon River in 1969.

Michigan and Wisconsin also stock brook, brown, and rainbow trout, normally less than 100,000 annually. Wisconsin has also made arrangements to obtain summer steelhead eggs from the West Coast to produce runs during the summer when sport fishing is at its peak.

Introduction of exotic species or re-introductions of fish into the Lake Superior Basin has been a popular management practice since late in the 19th Century. Most introductions have been salmonids, with various Atlantic and Pacific species. Of the early efforts, only rainbow and brown trout have had any noteworthy success. Attempts to re-establish grayling in Michigan have apparently not been successful. Recently, knowledge of life requirements for each exotic has been researched, providing a much better chance for success. Table 7 lists those species recently stocked in the basin.

Table 7.--Exotic Fishes Introduced into Lake Superior or the Lake Superior Basin.

Common Name	Scientific Name
Coho salmon	*Oncorhynchus kisutch* (Walbaum)
Chinook salmon	*Oncorhynchus tshawytscha* (Walbaum)
Pink salmon[1]	*Oncorhynchus gorbuscha* (Walbaum)
Kokanee salmon	*Oncorhynchus nerka* (Walbaum)
Splake	*Salvelinus fontinalis* x *S. namaycush*
Grayling[2]	*Thymallus arcticus* (Pallas)

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[1] Pink salmon were introduced accidentally from Canada and have developed a small spawning population along the Minnesota shore.

[2] Stocked in Otter River and Manganese Lake in Michigan. Stockings were apparently unsuccessful.

Regulations.--Regulation has been one of the primary methods of fishery management used by the States on the Great Lakes. Over the years, each State has evolved its own system of regulations. This has resulted in a patchwork of laws and regulations not always based on sound biological understanding of current problems. Most management agencies recognize that the original intent of many of these regulations has been lost over the years and they have taken steps to correct the situation.

Traditionally, commercial fishing regulations have been limited to adjusting regulations on closed seasons, fish size and gear, or by prohibiting the commercial removal of specified species. The latter was done with sturgeon in 1929. In 1962, the lake trout fishery was closed on Lake Superior. Lake trout commercial fishing has remained closed since then. However, some limited fishing with commercial gear has been allowed under special permits or contracts to provide biological information on the lake trout recovery and to evaluate plantings.

Commercial fishing regulations have undergone their greatest change within the past few years. The three States having jurisdiction over the U. S. portion of Lake Superior waters (Minnesota, Wisconsin, and Michigan) now have the authority to impose limited entry and catch quotas for commercial fishing. With this authority, the States can (1) limit the number of licenses, fishing vessels, and the amounts and types of gear used in the fishery; (2) designate areas where licensees may fish; and (3) specify species, pounds of fish taken, and seasons and depth fished. To date, some steps have been taken to initiate limited entry in Wisconsin, but conservatively and with few restrictions. Michigan has established a zone management program as its chief vehicle to regulate commercial fishing in its Great Lakes waters. Steps have also been taken in Michigan to initiate limited entry by establishing qualifications. These qualifications consider the fishing records of commercial fishermen for the previous three years and attempts to limit licenses to full-time fishermen.

Investigations.--Sound fishery management must be based on a good working knowledge of the fishery and ecology of a lake. Continuing investigations are recognized as the key to improved management. In order to reduce the number of fragmented or duplicated efforts in Great Lakes research, the Great Lakes Fishery Commission, with the assistance of Federal and State agencies engaged in fishery research and management, prepared a brief entitled "A Prospectus for Investigation of the Great Lakes Fishery". This was submitted to the U. S. Government in 1964. Recently another comprehensive evaluation was made of Great Lakes fishery research and management by the Great Lakes Fishery Commission, State agencies, and the Bureau of Commercial Fisheries, working through the Great Lakes Basin Commission's Fish Work Group. This report, entitled "An Analysis of Fishery Programs and Review of Current Plans for the Management of Fishery Resources of the Great Lakes", was submitted to the Great Lakes Basin Commission in March of 1969. Much of the material in this section has been taken from that report.

Over the years the Bureau of Commercial Fisheries has been the principal fishery research agency on the Great Lakes. With their experience, staff members of the Ann Arbor laboratory and the biologists located at various field stations around the lakes, have developed a considerable fund of knowledge regarding the fisheries and limnology of the lakes from which management decisions can be made for both commercial and sport fisheries.

The State agencies have recently been expanding their role in Great Lakes research. In addition to the Bureau of Commercial Fisheries stations, located at Ashland, Wisconsin, and Marquette, Michigan, each State has established a fishery station on Lake Superior. Stations are located at Marquette, Michigan; Bayfield, Wisconsin; and French River, Minnesota.

Investigations carried out by each agency have been concerned largely with a cooperative program to evaluate the recovery of lake trout stocks. However, each agency also carries out several other investigations of its own.

One of the major problems facing management agencies is the distribution of the fishery resources between the sport and commercial fishery. With recent changes in socio-economic patterns, there has been an increased demand upon management agencies to provide more and more sport fishing opportunities. Often this has resulted in institutional pressures against commercial fishing. However, the

States should be encouraged to give prudent consideration to the vital role commercial fishing plays in securing optimum utilization of the total fishery resource.

Joint Considerations.--Managment of the commercial and sport fisheries has been discussed separately up to this point. However, the prime responsibility appears to lie in managing the total resource for maximum public benefit. This most certainly includes an active role for both the commercial and the sport fishery components.

The management aspects designed to produce fish are essentially the same for both fisheries. One of the major problems facing management agencies, however, is the distribution of the fishery resource between the two. In this regard, sport and commercial fishing need not be considered strictly as competitive factions. Under proper management, the two complement each other. The most efficient management of the Lake Superior fishery depends upon wise and balanced utilization of the resources.

WILDLIFE MANAGEMENT BASE

Wildlife management is concerned with game production on all types of land or water capable of sustaining wildlife populations. This includes game produced on land devoted primarily to agriculture or forestry.

Management efforts have been generally directed along three major lines: (1) preservation of breeding stock by means of game laws restricting harvest, etc.; (2) artificial stocking; and (3) habitat improvement (Odum, 1959). Of the three, habitat improvement is now recognized as the most important management tool. It covers all aspects of habitat improvement, including food, cover, nesting area and loafing areas.

The overall quality of wildlife habitat depends heavily upon food, cover, and quality of water in the immediate vicinity. These factors, in turn, regulate the kind and amount of wildlife present in a given area.

During the early 1900's, the first pollution control statutes were initiated. These measures were originally designed to curtail diseases, such as typhoid. Later, pollution control measures were instituted which vested responsibility and authority in the State conservation departments to foster and protect wildlife.

Artificial stocking is useful in a new environment or in an area from which the species in question has been exterminated or in situations where dangerously low populations exist.

The Lake Superior watershed has generally good populations of most of its native wildlife species and few introductions have been attempted. Re-introduction of the fisher into Wisconsin and Michigan portions of the Lake Superior watershed took place between 1961 and 1963, in the Ottawa National Forest and in the Nicolet National Forest. These releases were primarily for control of the destructive porcupine, but also served to retain a rare animal in Wisconsin and Michigan (Stuewer, 1967). Most authorities now agree that all introductions must be considered with extreme care and that it is better to concentrate on management of native species.

In an area such as the Lake Superior Watershed, where most of the land area is forested, timber harvest and game management people can work together to produce even higher game populations. This area remains relatively free from the deleterious effects of water and air pollution, although use of persistent chlorinated hydrocarbon insecticides has occurred. Michigan and Wisconsin have recently been in the forefront among States opposed to the use of DDT and other insecticides which remain dangerous to life long after their original application. Michigan has already withdrawn nearly all registration of DDT. Maintenance of game stocks, songbird populations, and other forms of wildlife in this basin will depend to a large degree upon the success of various programs and new legislation. Foremost in importance among these are those dedicated to the proposition that the basin's air, soil and water should remain as free as possible from contamination by pollutants.

ECONOMIC BASE

General.--Residents of the Lake Superior Basin in Minnesota, Wisconsin, and Michigan, have traditionally relied on natural resources as the primary source of economic activity. Mining, lumbering, commercial fishing, and farming were historically the principal sources of income. However, these natural resource based industries have declined substantially over the past few decades. For example, mining in Michigan's upper peninsula now employs less than 10,000 workers, compared to the pre-1920 figure of 36,000. The lumber industry also has declined substantially.

Commercial Fishery.--In the face of the decline in other natural resource industries, the commercial fishing industry of Lake Superior continued as an important and stable source of economic activity through 1950. However, since the early 1950's it too has declined. The trend of total lake production is shown in Table 8. Table 9 shows production by species since 1879 and illustrates the change in size and composition of the catch in the period of record.

In recent years the value of the catch, as well as total production, has declined. Table 10 indicates average production and value for the lake's fishery since 1935. Figures 14 and 15 show the changing composition and value of the U. S. catch by species from 1953-1964. Since 1950, total catch and value have been decreasing. Figure 14 shows that herring has consistently been the major species in terms of poundage. Lake trout were most important in terms of value until 1957. However, since then, lake herring have been the mainstay of the Lake Superior commercial fishery, both in volume and value. Landings of all fish in 1964 were 48 percent below the total catch in 1945.

Table 8.--Lake Superior Fishery Production (U.S. & Canada): Average Pounds Per Year, Average Production of Pounds Per Acre, and Percentage of Total Great Lakes Catch

Years	Average Pounds Per Year	Average Pounds Per Year Per Acre	% of Total Great Lakes Catch
1879-1913	10,243,000	0.50	5.9
1914-1920	15,718,000	0.77	13.1
1921-1930	15,886,000	0.78	14.9
1931-1940	18,850,000	0.92	17.3
1941-1950	21,340,000	1.05	20.8
1951-1960	16,986,000	0.83	15.3
1961-1965	14,257,000	0.70	13.8
1914-1950	17,886,000	0.88	16.4
1879-1965	16,360,000	0.80	14.6
1941-1965	18,586,000	0.91	16.8

TABLE 9.--AVERAGE COMBINED PRODUCTION OF CERTAIN SPECIES FOR SPECIFIED PERIODS IN THE COMMERCIAL FISHERIES OF THE UNITED STATES AND CANADIAN WATERS OF LAKE SUPERIOR, 1879-1967, IN THOUSANDS OF POUNDS

PERIOD	STURGEON 2/	LAKE HERRING AND CHUBS	LAKE HERRING3/	CHUBS3/	SUCKERS3/	WHITEFISH	LAKE TROUT	NORTHERN PIKE	WALLEYE	OTHER	TOTAL
1879-1909 1/	98	1,133			83	2,830	5,323	15	163	312	9,957
1910-1919 1/	8	9,570			347	826	4,219	25	139	612	15,746
1920-1929	8	8,540			243	667	4,264	39	125	1,300	15,186
1930-1934	3	11,164			187	716	4,155	32	106	88	16,451
1935-1939	3	14,388			263	770	4,699	21	123	109	20,376
1940-1944	2		1/ 16,576	504	163	1,065	4,416	14	179	457	23,373
1945-1949	1		14,536	260	145	1,306	4,559	7	154	92	21,060
1950-1954	3		11,358	159	85	1,019	3,883	5	181	389	17,082
1955-1959	5		12,300	779	85	875	1,881	3	199	521	16,618
1960-1964	5		11,369	1,076	78	511	324	3	207	1,800	15,373
1965-1967	2		5,964	2,083	57	522	227	3	335	1,426	10,579
Largest Catch	224	18,558	19,271	2,196	347	5,178	7,352	115	378		
Year of Largest Catch	1885	1940	1941	1965	1917	1885	1903	1921	1966		

1/ Average for year of record

2/ Fishing prohibited in Michigan 1928-1950

3/ Catches of lake herring and chubs combined through 1940

FIGURE 14-ANNUAL CATCH FROM LAKE SUPERIOR BY MAJOR SPECIES, 1953-64

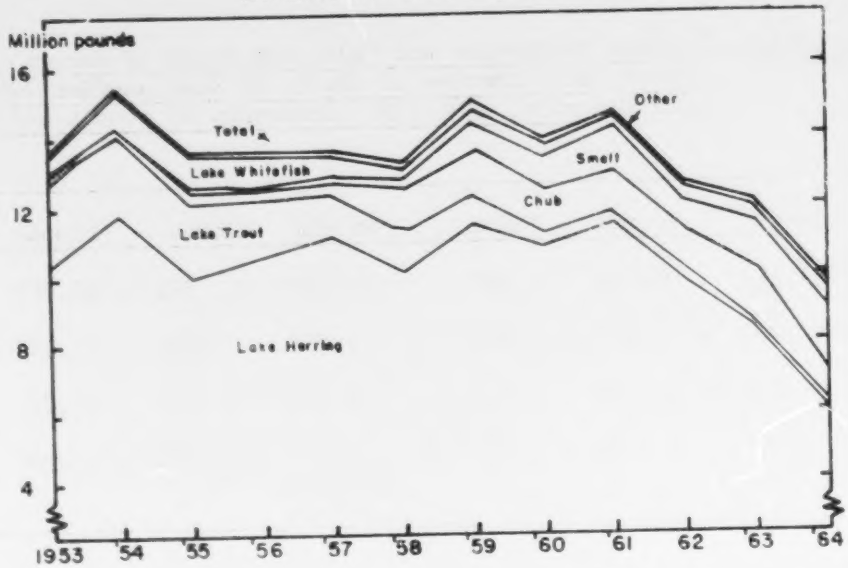
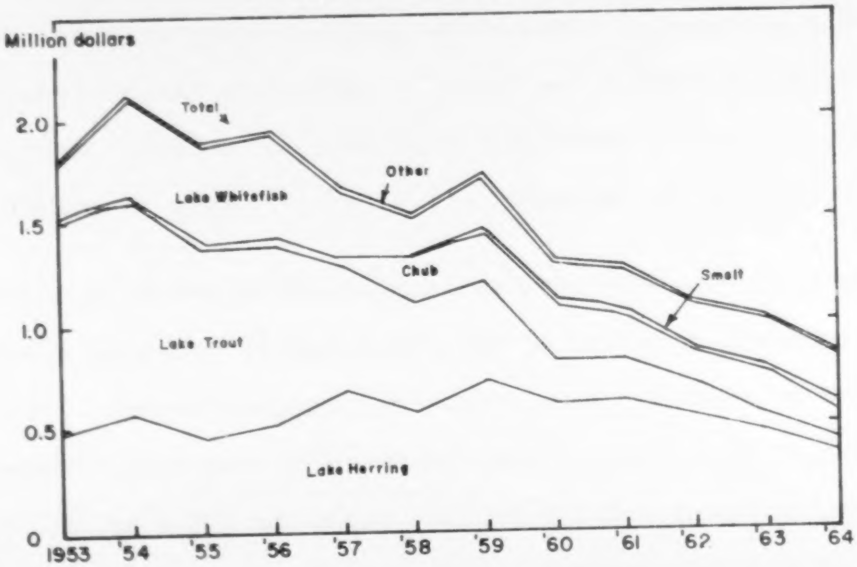


FIGURE 15-ANNUAL VALUE OF CATCH FROM LAKE SUPERIOR BY MAJOR SPECIES, 1953-64



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BUREAU OF SPORT FISHERIES AND WILDLIFE
REGION 3 MINNEAPOLIS, MINNESOTA

Table 10.--Average Production and Value for Years of Record in the Commercial Fisheries of the U. S. and Canadian Waters of Lake Superior, 1935-1966 (thousands of pounds and dollars).

Period	Pounds	Value	Pounds	Value	Pounds	Value
1935-1939	16,306	917	4,070	321	20,377	1,239
1940-1949	18,814	1,918	3,360	494	22,174	2,412
1950-1959	14,000	1,853	2,850	509	16,850	2,362
1960-1966	11,414	1,114	2,585	262	13,999	1,376

The decline in catch of high-valued species relative to the lower valued species has been pronounced. This is reflected in the average price per pound of fish received by Lake Superior fishermen. The average ex-vessel price declined steadily from over 15 cents per pound in 1950 to less than 9 cents per pound in 1964. When the prices are adjusted for inflation, an even greater change is evident.

The decline in both catch and value of the commercial catch has been accompanied by decline in the total number of commercial fishermen, with an especially sharp decline in full-time fishermen. From Table 11 it can be seen that the number of commercial fishermen has been undergoing a steady decline through the 1950's and 1960's, after a fairly stable period in the previous two decades. There has been an apparent trend for the number of part-time commercial fishermen to increase, probably by recruitment from the ranks of regular fishermen, whose numbers have decreased. Most of the fishermen

Table 11.--Commercial Fishing Operating Units and Productivity in the U. S. Waters of Lake Superior, 1922-1966.

Year	Number of Fishermen	Total Pounds Landed	Pounds Landed Per Fisherman	Total Value	Value of Catch Per Fisherman	Number* Vessels	Number Boats
1922	773	9,533,559	12,333	400,330	518	13	267
1929	1,184	17,148,194	14,483	835,254	705.45	51	404
1930	1,278	14,694,343	11,497	695,357	544.02	40	560
1931	1,200	11,281,125	9,400	627,314	523.17	40	479
1932	1,067	10,173,191	9,534	379,264	355.45	44	285
1934	1,202	17,533,200	14,526	722,754	601.29	41	295
1936	1,140	16,008,200	14,042	928,246	814.25	51	288
1937	1,227	16,011,200	13,049	918,859	748.87	61	468
1938	1,360	14,856,000	10,924	875,013	643.39	63	512
1939	1,491	16,782,900	11,256	921,723	618.19	62	567
1940	1,000	20,672,400	20,672	904,363	904.37	107	386
1950	1,029	12,584,300	12,230	1,977,354	1,921.63	173	361
1954	938	15,384,900	16,401	2,117,968	2,258.00	175	315
1955	857	13,581,100	15,847	1,883,876	2,201.00	166	319
1956	834	13,591,000	16,296	1,940,455	2,327.00	154	279
1957	823	13,564,500	16,482	1,655,624	2,012.00	146	295
1958	777	13,193,600	16,980	1,525,576	1,963.00	144	277
1959	877	14,955,700	17,053	1,713,699	1,954.00	136	265
1960	780	13,770,500	17,654	1,300,514	1,667.00	125	238
1961	742	14,748,800	19,877	1,263,515	1,703.00	114	221
1962	632	12,602,000	19,940	1,085,821	1,718.00	98	266
1963	608	12,125,200	19,942	1,011,027	1,663.00	97	278
1964	540	9,642,100	17,856	842,428	1,560.00	89	250
1965	542	8,748,000	16,140	1,062,873	1,961.00	85	249
1966	475	8,258,100	17,385	1,094,976	2,305.00	82	216

*A craft of five net tons or over is considered a vessel, all others are designated as boats.

today are part-time or casual fishermen, who use commercial fishing to supplement other sources of income. In 1966, the number of full-time fishermen was 62, with part-time and casual fishermen numbering 136 and 277, respectively.

Very few major capital expenditures are being made for upkeep and repair and most Lake Superior fishermen have been eroding their capital through their failure to maintain their depreciating equipment (BCF, 1966 and Frost, 1967). Few Lake Superior fishermen have gross sales adequate to cover all costs. In 1964, only 41 Wisconsin and Michigan fishermen had gross sales of more than $5,000, while just 16 had gross sales of over $15,000.

Harvesting.--Gill net fishing is by far the most important method of taking fish from Lake Superior. Over 90 percent of the landed catch from the lake is taken by this method. These nets are held in place with anchors. Lead weights are placed along the bottom of the net and metal floats are tied to the top of the net. Nets are lifted at varying intervals and the location and depth may be changed each day. Enclosed tugs ranging in length from 35 to 50 feet are used for gill net operations. The average or typical gill net tug is about 40 feet in length with a steel hull and a 110 h.p. diesel engine. Some tugs have wooden hulls. Ice is used for preservation, since no mechanical method of refrigeration is available on the vessels.

The tugs are enclosed because of the extreme weather in which the fishermen must operate. Considerable fishing may be done in temperatures of 0°F. or lower, when handling of wet nets in the open air would be a virtual impossibility. Most of the boats on the lake are not fully equipped with sonar or depth finders, ship-to-shore radios, automatic pilots or direction finders.

The days during which commercial fishermen can fish from the gill net tugs vary considerably in different parts of the lake. Both the degree of shelter from the wind and the depth of the bay influence the number of days the harbors or bays are open. A strong prevailing wind blowing out to the lake will tend to keep certain areas open. In other areas, however, the bays freeze over in mid-winter and remain frozen until spring. In general, ice on Lake Superior prevents commercial fishing with tugs from about February 1 through April 10. In areas where the ice is solid and does not drift, ice fishing is extensive. This is especially true in Whitefish Bay. Early opening in selected harbors is made possible by U. S. Coast Guard ice breakers. When the fishermen are unable to be on the water, they spend considerable time repairing or building nets and making necessary repairs or improvements.

A few fishermen on the lake have trout permits, issued for research purposes in conjunction with coordinated programs involving State or Federal agencies or the Great Lakes Fishery Commission. These individuals, however, also fish for other species. Most fishermen on the lake generally catch significant quantities of chub, herring and smelt, although some tend to concentrate on one or the other of these species.

Chub fishermen generally use bottom nets and set 8 to 10 boxes, with each box containing 1,600 to 1,800 feet of net. Thus, a typical chub fisherman will set 12,000 to 18,000 feet or about three miles of net per day. Herring fishermen use both bottom and float nets, depending on the season. The herring fisherman fishing with bottom nets sets approximately the same length of net as a chub fisherman. However, because of the somewhat greater danger of losing nets in the strong top current when fishing with float nets, only 6 to 10 boxes, each averaging about 900 feet of net per box, are set.

The approximate depth range of chub fishing is from 35-65 fathoms. Herring are caught at different depths at different times of the year. Spring and summer fishing is usually done in water 8 to 18 fathoms. In the fall, during spawning season, the fish go to the bottom in 3 to 4 fathoms of water and move out on the bottom in water up to 30 to 40 fathoms.

Pound nets are the next most important method of landing fish in the lake. Pound nets are a fixed type of entrapment made of fiber netting or chicken wire, supported by stakes or piling. These nets usually have a long wall which guides the fish into an entrance or heart, which in turn leads the fish into the pounds. The fish are then periodically dipped from the pound by dip nets.

From 1962 until 1968, the Bureau of Commercial Fisheries under contract with the Economics Development Administration, U. S. Department of Commerce, developed and operated a pilot program in order to test the feasibility of using bottom trawling as a method of commercial fishing in Lake Superior. The results of this study indicated that, based on the estimated production potential of chub and smelt and the availability of suitable bottom trawling grounds, the lake could support a two-vessel trawling operation. This was predicated on one vessel operating full-time in the central portion of Lake Superior for chubs and the second vessel operating part-time in the western section for smelt.

An operation of this sort would be based mainly on the bloater chub, which cannot be taken economically by gill nets. Currently there is limited trawling in the lake, but there does not appear to be much interest by most fishermen to undertake this method.

Processing.--Decline of the commercial fishery of the lake is also reflected in the statistics concerning the economic resources employed in processing and marketing this catch. The transition from fishing for the high priced to the lower priced species has created economic hardship for members of this segment of the commercial fisheries industry.

A good indication of the change in activity of the processing firms can be obtained by an examination of the input of raw product or the landed catch from the lake, which is handled almost entirely by these processors. The 1959 catch from the lake totaled 14,956,000 pounds, with a landed value of $1,714,000. In 1964, the total catch had declined to 9,642,000 pounds, with a landed value of $849,000. This was a 36 percent decline in quantity caught and over 50 percent decrease in value. As a result, many handlers have been hard-pressed to maintain their facilities. The number of processors or "first handlers" on Lake Superior declined from 21 in 1959 to only 10 in 1964. In 1959, these processors supported an estimated 190 man-years of work, with peak employment during the year of 527 persons. The number of man-years of employment declined to 82 in 1964, and peak employment was only 289 persons.

Problems which have hampered the processing segment of Lake Superior commercial fishing industry are: (1) lack of high-value species of demonstrated market acceptance; (2) lack of processing and manufacturing of desired convenience-type consumer product forms from available species; and (3) limited market potential for products of lower-valued species, due to market indifference, quality, or other reasons.

In recent years, the Bureau of Commercial Fisheries, with the assistance of university researchers and segments of the industry, has developed promising approaches in processing technology. Experimentation and study has concentrated on (1) means for improving the quality and extending the shelf-life of fresh (Emerson, Kazanas, Greig, and Seagran, 1966) and frozen (Greig, Emerson, and Fliehman, 1967) fish products; (2) greater mechanization of fish processing and handling (Emerson, 1964); (3) development of smaller portable equipment for fish reduction (Gnaedinger, 1965); and (4) the development of quality and sanitation guidelines as a consequence of extensive microbiological research (Dougherty and Seagran, 1966).

Whitefish and lake trout are readily adapted to consumer and institutional markets which prefer frozen fish products in fillet form. However, the manual methods traditionally used in processing these high-value species are not economically adapted to the smaller and less valuable chub and herring. As part of the study mentioned earlier (BCF, 1968), the Bureau of Commercial Fisheries employed mechanical means to fillet herring and chub and to dress smelt. Mechanical means to process these species as breaded and unbreaded products have also been employed. Frozen product shelf-life extension, accomplished by means of a chemical anti-oxidant additive and glazing treatment to retard the effects of oxidative rancidity has been successful in some cases. These methods allow the marketing of acceptable products that can be stored and distributed uniformly throughout the year. Presently underutilized species of Lake Superior could support a limited trawling fishery and a small commercial-scale, modern processing facility.

Marketing.--The Lake Superior Basin had 554,000 people in 1960 and this is expected to reach 880,000 by 2020. Though this represents a strong local market, the Chicago area is the major outlet for fish caught in the lake, with New York and Detroit also comprising important markets. Although data are not available to determine directly the quantitative importance of Chicago as a market for Lake Superior species, Table 12 shows the amount of all freshwater fish products received in Chicago relative to salt water fish and shellfish products. Even though there has been a rather rapid decline in the receipts of freshwater species since 1956, a similar decline in the salt water fish and shellfish species has also been experienced. As a result, freshwater fish as a percentage of total receipts in Chicago over the period from 1956 to 1964 have declined only slightly.

The decline in the total receipts has resulted in a decrease in the number of buyers in Chicago. Thus, the Lake Superior fisherman has fewer alternative outlets for the disposition of his fish. While most of the other Great Lakes have a fishery base that supplies the industrial as well as the food fish market, nearly all of the Lake Superior catch is sold for human consumption. A large percentage of this market prefers frozen fish products in fillet forms, and the market for these products has remained good, despite the decline in the choice species. It is the supply, rather than the demand, that has been the controlling factor of production for the preferred species.

Table 12.--Receipts of Fresh and Frozen Fish and Shellfish Products in Chicago, 1956-64[1]

Year	Million pounds				Freshwater Fish as Percentage of Total
	Fresh-water Fish	Salt Water Fish	Shellfish	Total	
1956	46.2	32.0	28.1	106.4	43.5
1957	39.1	27.8	24.3	91.2	42.9
1958	39.6	30.1	22.7	92.3	42.8
1959	39.3	26.1	27.1	92.5	42.5
1960	37.0	25.6	24.4	87.0	42.5
1961	32.7	22.0	23.4	78.1	41.8
1962	30.6	22.4	21.4	74.5	41.1
1963	26.4	18.8	18.0	63.1	41.7
1964	24.7	18.0	17.3	60.0	41.1

[1] Canned, preserved, pickled, and smoked products not covered.

There is need to develop consumer markets for additional species in the Lake Superior fishery. A pilot project conducted by the Bureau of Commercial Fisheries found that such a market could be developed for smelt, herring and chub fillets, both breaded and unbreaded (BCF, 1968). Full-scale marketing of these products has not yet developed and will require full promotional effort suitable for new product introduction, including merchandising incentives and advertising allowances.

Institutional Problems.--Any review of the problems of the commercial fishery must take the institutional framework into consideration. The implementation of concepts like limited entry and achievement of balanced utilization of the total fishery resource--both commercial and sport--are objectives that must be realized either through the existing institutional framework or through evolvement of a new one. The State fish and game agencies in the three States involved, as well as the Province of Ontario, all have the necessary power to regulate sport and commercial fisheries. The procedures and provisions for consideration of the legitimate interests of all parties concerned differ from State to State and in Canada. Areas of concern include (1) criteria for determining who remains and who is eliminated in a limited entry fishery, and (2) provisions for compensating for the investments of those who are eliminated. These determinations not only differ but are subject to evolution and development. The institutional situation is further complicated by the existence of interstate and international bodies such as the Great Lakes Fishery Commission, the Great Lakes Commission, and the International Joint Commission, which have varying degrees of responsibility for planning, coordination of research, and in the case of the IJC, regulation of water levels and other matters. From the fisheries standpoint, including commercial fisheries, the state and provincial fish and game agencies remain the central fact of institutional life. Implementation of a fair and rational system of limited entry based on sound biological and economic information is now largely within their powers and prerogative.

In a larger framework, however, the secondary network of commissions and other institutional arrangements referred to above are very important, particularly in terms of approaching common problems such as environmental alteration, research priorities and improvement of water quality. Realization of the goal of balanced utilization of the total fishery resources of Lake Superior will require increasing attention to, and coordination with, the institutional framework if fisheries, both sport and commercial, are to maintain a significant role in overall development.

Sport Fishery and Wildlife.--The economic base of sport fishing and hunting entails an analysis of the monetary outlay of the sportsman, as well as the intangible esthetic values which are attributable to fish and wildlife. During a period of overall decline in the commercial fishery, there has been a tremendous increase in recreation resource use, especially in sport fishing. Of the many types of recreation available in the basin, fish and wildlife are probably the most important. These resources provide many thousands of man-days of fishing and hunting. The non-consumptive values of wildlife are perhaps even more important in their power to draw people to an area such as the Lake Superior Basin.

Through various studies and questionnaires, estimates of the amounts spent on fishing and hunting equipment, travel, food and lodging, and other related monetary values have been derived. The values in Table 13 represent national averages for fisherman expenditures.

Table 13.--Average Expenditures for Fishing and Hunting - National Averages for 1955, 1960, and 1965*

	1955	1960	1965
Big Game	$ 73	$ 55	$ 64
Small Game	50	60	58
Waterfowl	60	46	53
Fishing	77	95	89

*BSF&W: Circ. 44, 1955; Circ. 120, 1960; Publ. 27, 1965.

A 1955 mail survey taken in Minnesota to determine the economic values of sport fishing revealed that the individual license holder spent $84 per year. This compares closely with the national average of $77 for that same year (Scheftel, 1958).

Using the 1965 figures from Table 13, the total spent by 200,000 basin hunters and more than 300,000 basin fishermen was approximately 39 million dollars. This represents a substantial portion of the total amount spent on the tourist and recreational resources. It also represents an estimated 5,520,000 fisherman-days and 2,740,000 hunter-days of recreational activity.

WATER QUALITY ASPECTS

Open Waters

The open waters of Lake Superior are of generally high quality. They have not yet been greatly changed by human activity (Beeton, 1965). Figures 6 and 7 show the changes in the chemical characteristics of the lake since 1880. The slight drop in dissolved solids is not considered significant. The slight decrease in the sodium-plus-potassium level appears to be due to changes in analytical methods, rather than actual changes in the chemical levels. Similar trends data are not available for critical items such as nitrogen, phosphorus, pesticides, detergents or heavy metals.

Shipping has been responsible for minor water quality degradation in the open waters and harbor areas of Lake Superior. Oil discharges, bilge wastes and garbage from commercial vessels plying the lake have created problems from time to time. However, recent enforcement programs have become more stringent and the problem is not considered acute.

Recent reporting on their pesticide monitoring program by Wisconsin Department of Natural Resources involving Lake Superior fish showed average concentrations of total DDT (DDT, DDD, and DDE), of greater than 1 ppm.

Recent analysis by the Bureau of Commercial Fisheries regarding pesticide concentrations in Lake Superior fish showed concentrations of total DDT (DDT, DDD and DDE) varying from 0.22 ppm in sculpins to 7.4 ppm in large lake trout. For most species of sport and commercial importance (except large lake trout) concentrations were in the 1 to 2 ppm range. Overall concentrations of pesticides in Lake Superior fish are about one-third of those found in Lake Michigan fish of similar size.

Table 14 presents water quality criteria for open waters of Lake Superior as summarized at a water quality conference held in Duluth, Minnesota, in May 1969 (FWPCA, 1969). For some parameters these criteria are lower than the existing water quality.

Because of the limited data available regarding water quality of the open lake, a concerted effort should be made soon to secure needed open lake data so that any needed corrective measures could be reflected in revised standards.

The Second Session of the Lake Superior Enforcement Conference was held in Duluth, Minnesota, April 29-30, 1970. The conferees referred the report of the Lake Superior Water Quality Technical Committee back to that committee. The committee was requested to determine which of the proposed water quality guidelines for the open waters of Lake Superior can be recommended for early adoption as water quality standards. The committee was also asked to recommend a program for developing specific additional criteria. Also, the States are to report on finalized time schedules for compliance with the conference recommendations regarding all discharges. These reports are to be ready for the next session of the Enforcement Conference, which will be held early in August 1970.

Inshore Waters

United States.--The water quality generalizations made for the open lake are appropriate for most of the inshore waters. The widespread indications of change and deterioration observable

Table 14.

LAKE SUPERIOR OPEN WATERS*
WATER QUALITY CRITERIA AND DESIGNATED USES
MICHIGAN, MINNESOTA, WISCONSIN

STATE	DESIGNATED USES	COLIFORM GROUP	DISSOLVED OXYGEN	SUSPENDED, COLLOIDAL AND SETTLEABLE MATERIALS	FLOATING MATERIAL, RESIDUES, DEBRIS AND MATERIAL OF UNNATURAL ORIGIN	TOXIC AND DELETERIOUS SUBSTANCES	TOTAL DISSOLVED SOLIDS	NUTRIENTS	TASTE AND ODOR PRODUCING SUBSTANCES	TEMPERATURE	pH	RADIOACTIVE MATERIALS
MICHIGAN	Domestic Water Supply Industrial Water Supply Recreation: - Whole Body Contact - Partial Body Contact Fish, Wildlife and Other Aquatic Life: - Intolerant Fish Cold Water Species - Intolerant Fish Warm Water Species Agricultural Commercial	The average of any series of 10 consecutive samples shall not exceed 1000 organisms per 100 ml nor shall 20% of samples exceed 5000/100 ml Fecal coliforms for the samples } 100/100 ml	Cold Water Intolerant Species { 6 mg/l at any time Warm Water Intolerant Species Avg. Daily Value { 5 mg/l Any Single Value { 4 mg/l	No objectionable unnatural turbidity, color, or deposits in quantities sufficient to interfere with designated use	No evidence of such material except of natural origin No visible film of oil or globules of grease	Conform to current USPHS Drinking Water Standards, except: Cyanide: } 0.2 mg/l Chromium: } 0.05 mg/l Phenols: Mo. Avg. } 0.002 mg/l Single Value } 0.005 mg/l Not to exceed 1/10 of the 96-hour TL_m obtained from continuous flow bioassays where the dilution water and toxicant are continuously renewed except that other application factors may be used in specific cases when justified on the basis of available evidence and approved by the appropriate agency	Total Dissolved Solids: } 200 mg/l Chlorides: Mo. Avg. } 50 mg/l	Nutrients originating from industrial, Municipal or domestic animal sources shall be limited to the extent necessary to prevent adverse effects on water treatment procedures or the stimulation of growth of algae, weeds and slimes which are or may become injurious to the designated use	Concentrations of substances of unnatural origin shall be less than those which are or may become injurious to the designated use Phenols: Mo. Avg. } 0.002 mg/l Max. Concentration for a Single Value } 0.005 mg/l	Intolerant Fish Cold Water Species 70°F Maximum } 10°F Increase Intolerant Fish Warm Water Species 85°F Maximum } 15°F Increase when ambient temperature is less than 35°F } 10°F Increase when ambient temperature ranges from 36°F to natural maximum See Footnote Below[1]	Range of 6.5 - 8.8 } 0.5 unit change within range	} 1000 pc/l of gross beta activity in absence of Sr-90 and alpha emitters If this limit is exceeded the specific radionuclides present must be identified by complete analysis in order to establish the fact that the concentration of nuclides will not produce exposure above recommended limits established by the Federal Radiation Council
MINNESOTA	Domestic Consumption (1B) Fisheries and Recreation (2A) Industrial Consumption (3A)	} 50 MPN/100 ml	Oct-May { 7.0 mg/l Jun-Sep { 6.0 mg/l	Turbidity } 5.0 units No discharge from unnatural sources so as to cause any nuisance conditions	Oil } Trace No discharge from unnatural sources so as to cause any nuisance conditions	[} - mg/l] Arsenic 0.01 Barium 1.0 Cadmium 0.01 CCE 0.2 Chromium Trace Copper Trace Cyanide Trace Fluorides 1.5 Lead 0.05 Manganese 0.05 Nitrates 45.0 Selenium 0.01 Silver 0.05 Zinc 5.0	Total Dissolved Solids: } 500 mg/l Chlorides: } 50 mg/l Sulfates: } 250 mg/l Hardness: } 50 mg/l	No discharge from unnatural sources so as to cause any nuisance conditions	Threshold Odor: Number } 3 Phenols: } 0.001 mg/l	No Material Increase	Within range of 6.5 - 8.5	Gross beta concentration not to exceed 1000 pc/l in known absence of alpha emitters and Sr-90 Also: Not to exceed the lowest concentrations permitted to be discharged to an uncontrolled environment as prescribed by the appropriate authority having control over their use
WISCONSIN	Public Water Supply Industrial and Cooling Water Commercial Shipping Recreation: - Whole Body Contact Beach areas Fish and Aquatic Life Trout Waste Assimilation	Arith. Avg. } 1000/100 ml Max. } 2500/100 ml during recreation season	{ 80% Saturation nor { 6 mg/l at any time } 1 mg/l change	Substances that will cause objectionable deposits in the bed or on the shore of a body of water shall not be present in such amounts as to create a nuisance	Floating or submerged debris, oil, scum or other material shall not be present in such amounts as to create a nuisance	Substances in concentrations or combinations which are toxic or harmful to humans shall not be present in amounts found to be of public health significance, nor shall substances be present in amounts, which by bioassay and other appropriate tests, indicate acute or chronic levels harmful to animal, plant or aquatic life	Mo. Avg. } 500 mg/l Max. } 750 mg/l at any time	Materials producing color, odor, taste or unsightliness shall not be present in such amounts as to create a nuisance	Materials producing color, odor, taste or unsightliness shall not be present in such amounts as to create a nuisance	64°F Max. Change from natural unpolluted background } 5°F Rate of Change } 2°F/hour	Within range of 6.0 - 9.0 } 0.5 unit change if natural values are above 8.5 or below 6.5	Intake water supply will be such that by appropriate treatment and adequate safeguards it will meet PHS Drinking Water Standards, 1962

*Criteria and Uses as of March 1, 1969

) Greater Than } Not Greater Than
(Less Than { Not Less Than

Where designated uses have different criteria the most stringent criteria are listed.

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[1] For the Great Lakes and connecting waters no heat load in sufficient quantity to create conditions which are or may become injurious to the public health, safety, or welfare, or which are or may become injurious to domestic, commercial, industrial, agricultural, recreational or other uses which are being or may be made of such waters, or which are or may become injurious to the value or utility of riparian lands, or which are or may become injurious to livestock, wild animals, birds, fish or aquatic life or the growth or propagation thereof.

in the inshore waters of the other Great Lakes are, for the most part, not apparent in Lake Superior. There are exceptions, however. These include severe water quality problems in the Duluth-Superior area and siltation from a region in Wisconsin where red clay causes problems. There are also smaller local situations, insignificant with respect to the vast expanse of the lake, but important as indicators of potential trouble along the south shore.

Heavy pollution loads caused by paper and steel mills and other industrial and municipal wastes dumped into the St. Louis River and Superior Bay, have created water quality problems in the Duluth-Superior area. Though it is difficult to directly trace the effects of these inputs for more than a few miles into the lake, it appears that they might be contributing to above average nutrient levels in waters near the Apostle Islands and along the western side of the Keweenaw Peninsula.

Another potentially serious problem exists at Silver Bay on Minnesota's North Shore. It involves the taconite tailings which are being dumped into Lake Superior by Reserve Mining Company at Silver Bay, Minnesota.

The deposition of taconite tailings has the potential to harm aquatic life, including fishes, in Lake Superior. Pollution from this source is unquestionably increasing the turbidity and introducing foreign materials, the effects of which are not yet fully understood.

The extent to which fish habitat is being altered, and fish food supplies locally reduced, is still not known. However, Pontoporeia sp., bottom organisms known as scuds or freshwater shrimp, were reduced by about one-half from 1949 to 1968. This covers the period during which the study area had been subjected to tailings deposits. Pontoporeia are an important source of food for young lake trout, and some reduction in trout numbers has likely occurred because of the reduction in food supply. The Minnesota study calculated this reduction at . . . "5 percent or less for the area considered, . . ." (Skrypek, Burrows, Bishop and Moyle, 1968). This study concentrated upon the effects of Pontoporeia disappearance insofar as they related to adult fish. The effects upon small lake trout, which depend heavily upon Pontoporeia, would undoubtedly be greater. Food supplies for smelt and whitefish have likely declined in this area also, but the extent remains undetermined. There is some indication that the decline in Pontoporeia has been accompanied by an increase in oligochaetes in the area where deposition of fine taconite tailings occurred (Skrypek, et al, 1968). Oligochaetes are of little value as fish food.

Another possible adverse effect of deposition of taconite tailings on the bottom relates to hatching success of fishes depositing eggs in the taconite deposition zone. Hatchery success could be expected to be lowered in this area.

Bioassay studies at the Bureau of Sport Fisheries and Wildlife's Fish Control Laboratory in LaCrosse, Wisconsin, revealed that the taconite tailings were harmful to rainbow trout sac fry and to water-fleas (Daphnia). More bioassays are needed. Other biologically oriented studies must be intensified and accelerated if these research findings are to make their full contribution in better defining the problem.

Even though the answers to many questions concerning the detailed effects of taconite pollutants on fish and other aquatic life must await further study, the conferees of the Lake Superior Pollution Conference concluded that damage had taken place and that alternative means of disposal should be undertaken. The Fish and Wildlife Service, the Federal Water Quality Administration, the affected states, and the citizenry in general have a substantial interest in the outcome of this matter and the problem should be resolved as soon as possible.

The studies of the Federal Water Quality Administration have already shed some light on this complex problem. New findings from their on-going program of research on taconite tailings are expected to be released as they become available. They will undoubtedly provide part of the basis for future decisions regarding any necessary modifications in the taconite disposal process.

As a result of the May 13-15, 1969, and September 30, 1969, conferences on Pollution of Interstate Waters of Lake Superior and its Tributary

Basin (Minnesota-Wisconsin-Michigan), the Federal Water Quality Administration and the states were requested to keep the discharge of taconite tailings to Lake Superior from the Reserve Mining Company, E. W. Davis Works, under continuing surveillance and report to the conferees at six-month intervals on any findings that interstate pollution is occurring or is likely to occur.

In addition, Reserve Mining Company was requested to undertake certain engineering and economic studies. These studies would determine possible ways and means of minimizing deposition of taconite tailings into Lake Superior. The requested report is to include a time-table for accomplishment of the corrective measures. In the meantime, "lake sampling and effluent and operational information shall be furnished monthly by the Reserve Mining Company to the Minnesota Pollution Control Agency. Reserve Mining also is to inform the Minnesota Pollution Control Agency of the line of study they intend to pursue, and the Minnesota agency will make this information available to the conferees." (Partial quotation from the conference summary issued by the Secretary of Interior on January 26, 1970).

A progress meeting was held April 29-30, 1970, at Duluth, Minnesota, to receive the report of Reserve Mining Company. The company submitted 19 preliminary proposals for alternate methods of disposal. They will hold discussions with representatives of the conferees to discuss the acceptability of the various proposals. The company was also requested to submit an acceptable final plan and time table for modifying their discharge, with such information to be made available for the next session of the conference early in August 1970.

In view of the many potential problems being engendered from deposition of taconite in Lake Superior, new permits issued by the Corps of Engineers are expected to be more restrictive.

Canada.--A good example of the effects of pollution on the fishery resources of Lake Superior is found on the Canadian side of the lake. Ryder believes that the recent elimination of the walleye fishery in Nipigon Bay can be attributed to industrial pollution originating from a kraft paper mill. High concentrations of total solids and dense sedimentation of wood fibers created an environment unfavorable to mayfly nymphs and amphipods, both of which are important items for the walleye in Lake Superior. When these organisms became scarce, the walleye decreased rapidly in numbers (Ryder, 1968). Substantial amounts of pollution also originate from pulp and paper mill wastes at Thunder Bay, Ontario.

Tributaries

Overall water quality of Lake Superior tributaries is very good. Most of these streams originate from relatively infertile and sparsely populated lands. Only two major problem areas exist in the United States tributaries of the basin. These are (1) the lower St. Louis River, including Duluth-Superior harbor, and

(2) the tributary streams involving the red clay region of northwestern Wisconsin.

Minnesota Streams.--The tributaries north of the French River on Minnesota's North Shore are essentially undisturbed by man and the fish populations remain healthy.

The drainage system of the St. Louis River has a more concentrated human population and the land use is more intensive. Several mining communities, located in the northwest portion of the basin, add partially treated effluents to the river. These sources aggravate siltation problems in the river (Minnesota Department of Conservation, 1964).

In general, the St. Louis River above Cloquet, Minnesota, has adequate quality to support good populations of fish. However, industrial effluents, plus a heavy load of partially treated domestic sewage, all from Cloquet, severely contaminate the river. The heavy pollution load limits most forms of water use from Cloquet to Duluth Bay. Some boating occurs near Duluth, but fishing is very limited. Fish still surviving in the river or in the hydroelectric reservoirs have acquired a bad flavor from the water. The problem occurs with fish taken downstream from Cloquet to Duluth and for some distance into Lake Superior (Minnesota Department of Conservation, 1964).

The biochemical oxygen demand of the pollutants discharged into the river intensifies the danger of fish kills from low oxygen concentrations. Several extensive kills have occurred in recent years, with 1956, 1958, and 1969 being outstanding examples. This danger exists each year during low flow periods in late summer.

One recorded fish kill resulted in 1954 from chemicals released into the river. Phenols released into Silver Creek, which is a tributary to the St. Louis River, were the cause of this fish kill (Hassinger, 1967). Most pollution effects are more subtle, but it is recognized that a general degradation of aquatic life has occurred, attributable to various pollutants in the St. Louis River. Bottom organisms have changed from intolerant to tolerant species which do not need high quality water to survive (Hassinger, 1967).

Various industries in Duluth, Minnesota, and Superior, Wisconsin, sewage plants from both cities, and untreated sewage from cargo ships using the harbor all contribute to the pollution problem in Duluth-Superior harbor.

Wisconsin Streams.--Most Wisconsin streams situated within the Lake Superior watershed are valuable for fishing and other outdoor recreational purposes. The most famous of these streams is the Brule River, which is famous for its trout fishing.

Problems of water quality in the Wisconsin portion of the drainage are of generally minor significance. Northwestern Wisconsin soils are predominantly red clay, which is highly erodable. With increased farming, logging, and wood construction activities, clay in suspension is beginning to cause serious problems in some streams. The Middle and Amicon Rivers are examples of streams carrying a large sediment load into Lake Superior. Limited studies on the Bad River near Odonah, Wisconsin, indicated a long term average sediment yield of 278 tons per square mile. Siltation of highly productive trout streams is occurring. Turbidity and siltation adversely affect both the habitat and the biological life processes of the fish. In addition, turbid streams are unattractive and difficult to fish successfully (Wisconsin Department of Resource Development, 1962).

Local water quality problems are few. However, such areas as the Ashland, Wisconsin, harbor show signs of minor pollution from ore boat spillages and industrial plants.

Michigan Streams.--Water quality problems in the Michigan portion of the Lake Superior drainage are generally minor. Problem areas are generally localized around population centers on tributary streams.

Wastes from paper and pulp mills at Ontonogan and Munising, Michigan, cause local water quality problems in streams and estuaries. Minor pollution has been reported at the Marquette, Michigan, harbor. Shipping discharges from steam electric plants, and inadequately treated sewage have been cited as sources. Sedimentation from Michigan streams is not as severe as from Wisconsin tributaries.

Generally, streams west of the Keweenaw peninsula produce the greatest sediment discharges. The Waiska River near Sault Ste. Marie also discharges fairly heavy sediment loads during spring floods.

LONG RANGE TRENDS IN WATER QUALITY

In a sense, the material covered in the report up to this point can be considered as a necessary prelude to consideration of the water quality relationships, which are the chief concern of the Federal Water Quality Administration. This involves attempts to project long-range water quality trends, based upon limited detailed information on changes in water quality and considering the relationships of these trends to the fishery resources. This means employing the best available estimates and reasoned judgments representing the consensus of informed opinion, where full scientific knowledge is lacking. An attempt has been made to strike a balance between the rigorous demands of scientific analysis on the one hand and the obligations of conservationists to preserve and enhance the welfare of the fishery resource on the other.

Open Lake.--In the open waters of Lake Superior, water quality data is largely limited to data on concentrations of certain dissolved solids over a period of years. These are not necessarily chemicals that are particularly important in terms of their effects on fish and aquatic organisms, at least at existing and projected levels of concentration. They do, however, give a useful indication of what may be happening to other concentrations of more critical water quality items for which accurate long-range data are not available.

Based on the limited data available, there has apparently been little buildup of dissolved solids in the open lake. It does not necessarily follow that this is also true for the numerous other substances for which good long-range data are not available. These include such critical elements as nitrogen and some of the heavy metals. Present levels of these substances are low and rates of increase of most of these foreign materials should also be low, if limited human population and industrial development densities continue. Concentrations and buildup of pesticides may be another story. Investigations by BCF scientists indicate levels of DDT and dieldrin in the flesh of Lake Superior fish one quarter to one-third of Lake Michigan fish. While comparatively low, these concentrations have accumulated over the relatively few years since widespread use of these pesticides began. Projections on this basis would be cause for concern.

Overall, however, the open waters of Lake Superior still represent a huge reservoir of waters of unusually good quality. Currently, discharge from this natural reservoir into the rest of the Great Lakes system at the average rate of over 73,000 cfs exerts a major stabilizing effect in maintaining water quality levels in some of the lower lakes, particularly Lake Huron.

Inshore Waters.--Experience and studies in the other Great Lakes have demonstrated the key role of the inshore waters as indicators of water quality change. The sheer volume of open lake waters can mask the effect of pollution inputs for many years, until cumulative total begins to have an impact. The indications of trouble first show up in localized inshore water areas.

The inshore waters of Lake Superior do not as yet exhibit widespread indications of incipient water quality deterioration. There are important localized exceptions, however. One prime example is dumping of taconite tailings at Silver Bay, Minnesota. Paper mill wastes at Nipigon Bay, Ontario, plus municipal and industrial wastes from the Duluth-Superior area, and a few other population concentration points in the basin are other examples. From the standpoint of fish and aquatic life, these scattered signs of trouble in the inshore waters should be read for what they are. They constitute symptoms and warnings that decisions should be made now as to what future water quality trends are to be encouraged, and steps taken accordingly. Retention of Lake Superior's exceptionally high quality waters and aquatic life environment is easier to attain than restoration of a degraded lake.

DEMAND

Demand for Commercial Fishery Products.--The products of the Lake Superior commercial fishery are consumed largely outside the basin. Therefore, analysis of needs cannot be confined to this basin or even the combined basins of all the Great Lakes. Dependence must be placed largely on national statistics and trends, combined with regional production figures.

Based on these factors, future demand for fishery products from the Great Lakes has been projected to the year 2020 (Table 15).

Table 15.--Projected Demand for Fishery Products from the Great Lakes (Millions of Pounds)

Year	Total Demand (Edible and Industrial Products)
1960	104.7
1980	147.0
2000	228.0
2010	303.0
2020	412.5

The projections consider population growth, disposable personal income, and an income elasticity of demand for edible fishery products. Thus, consumption of edible fishery products is expected to increase on a per capita basis with the rise in disposable income. Regarding the consumption of fish, the effects of increasing future per capita income will likely not be offset in the future to the extent that has occurred in the past. The factors of declining prices and increasing supplies of competitive products such as poultry, beef and other animal proteins, have likely been reversed. Also, programs now underway or being considered in the areas of product development, improved marketing and handling, and consumer education are likely in themselves to result in an increase in demand. Industrial fishery products are included in the projected figures for total demand. Large increases in chicken broiler production have been considered, since the bulk of fishmeal is consumed in that industry.

As the demand for Great Lakes fish products increases, Lake Superior will not be able to maintain the 16 percent share of the market it has held over the past 25 years. By the year 2020, this would require a production of 66 million pounds from Lake Superior. Due to reasons stated previously, total lake production is limited. Therefore, the projected value of the Lake Superior fishery must be based more on quality than on increased output.

A large part of the increased demand for fish will be for high quality food fish such as lake trout and whitefish. Demand for these species will likely increase even more than the average increase indicated in Table 15. With lamprey control and proper management, it is expected that these two species will again become important in the lake's commercial catch. Returns from these two species, in conjunction with other prized food fish, will compose a large share of the commercial fishery revenue. Recent successes with salmon introductions into the Great Lakes have indicated that Lake Superior also may be able to support a salmon population that can be managed for both recreational and commercial fishing.

Future development of Lake Superior's fishery will also depend upon increased utilization of some of the already established species. A recent project by the Bureau of Commercial Fisheries demonstrated the feasibility of marketing both breaded and unbreaded chub, herring and smelt. The study indicated that there is a consumer market for these species (BCF, 1968). In addition, there is an industrial market demand for fish species not sold in the regular consumer channels.

Thus, there are two major lines of development for the Lake Superior fishery in meeting future demands: (1) re-establishment of the lake trout and whitefish fishery, together with increased production of other highly prized food fish such as salmon, plus a return of herring production to previous levels; and (2) increased production of smelt, chubs and other underutilized species.

Demand for Sport Fisheries and Wildlife. --In 1960, there were 225,000 fishing licenses sold in the counties within the Lake Superior Basin. Of this total, approximately 100,000 were to nonresidents. This is an indication of the great demand for sport fishing from outside the basin. There is also a considerable influx of resident fishermen from outlying areas in the three states. By 1965, it is estimated that there were approximately 300,000 fishermen using this basin.

As populations expand, total demand for high quality fishing will increase. From 1950 to 1960, increases in fishing license sales averaged about 3.5% per year in the United States (BSF&W, 1962). The Lake Superior watershed is a logical area to service much of this new demand. Total man-day demand for fishing, based on 18.4 man-days per fisherman per year (BSF&W, 1965), was approximately 5,520,000 man-days expended in the Lake Superior Basin in 1965. This demand is expected to increase to 8,400,000 man-days by 1980 (BSF&W, 1962) and to increase to 20,000,000 by the year 2020! Approximately 200,000 hunting licenses were sold in the basin in 1965. Most of these were issued to residents of the basin counties. Some influx of hunters from outlying counties in the three states also occurred. Out-of-State hunters are relatively unimportant in terms of numbers. Based on an estimated 200,000 hunters and an average activity rate of 13.7 hunter days (BSF&W, 1965), the total man-day demand for hunting in the Lake Superior Basin in 1965 is estimated at 2,740,000 man-days. This figure will increase to an estimated 4,000,000 man-days by 1980 and to 5,500,000 by 2020.

ECONOMICS-ORIENTED REQUIREMENTS

Analysis of the historical and current commercial fishery situation in Lake Superior shows it sharing many of the basic economic problems of the total Great Lakes fishery. Reduction of the high-valued species by the lamprey and increasing abundance of low-priced species has substantially reduced the margin of profitability possible with traditional gear and marketing methods. Historically, many of the commercial enterprises were small and labor intensive, relying on selective production of lake trout, whitefish and herring with little or no requirements for further processing. However, production costs with gill nets and pound nets are generally prohibitive for taking the species now most abundant, such as smelt and chubs. When the final forms of fishery products change to those requiring volume harvesting, scattered individual enterprises are unable to achieve the degree of effectiveness necessary to compete in the market. This problem is aggravated by fluctuations in abundance and the increasing trend towards part-time fishing, which tends to limit further the fisherman's inclination or ability to undertake significant capital improvements.

Solutions to these economics-oriented problems involve consideration of a number of inter-related factors. Economic studies are needed to relate the biological factors of species composition, abundance and stability to the costs and efficiency of various harvesting and processing methods. Also, the possibility of centralized or cooperative processing and marketing facilities should be examined. The value of balanced exploitation of available stocks in improving the recreational as well as the commercial fisheries must not be overlooked in achieving maximum social and economic benefits from the Great Lakes fisheries.

Increased knowledge concerning the economics of an expanded charter boat fishery, new species of sport fish, and new access to remote areas is needed to properly evaluate future sport fishing. Charter boats involve substantial investments. Improved harbors and access facilities will become necessary as the number of charter boats increases.

The success of exotic species introductions will in turn depend on the success of propagation, lamprey control, and other programs, some of which will have to be expanded. Some of these programs should be amortized, since benefits will not be immediate, but will likely continue far into the foreseeable future.

Increasing demand for fishing will create a need to open additional areas or improve existing access sites. This is especially true in some portions of Minnesota and Michigan. There are few places along the Minnesota shore of Lake Superior where fishermen can launch or moor a boat. Many upland areas and upper reaches of some of the tributaries are inaccessible to hunters and fishermen. Similar problems exist in Michigan. Somewhat better harbor facilities exist in that State, but some inland areas are still very remote.

Hunting demand is not expected to increase as fast as fishing demand, but there will be a need to furnish access to new areas in order to meet the increased demand. Presently, game is underutilized, but by the year 2000, more intensive management programs will be needed.

Some of the problems of the commercial fishery could be solved by focusing on modernization of the industry, making it responsive to changing consumer requirements and needs. This requires greater research effort, promotional activity, quality control and cooperation among government, industry, universities, and the private sector.

Water quality goals for Lake Superior should include setting and maintaining whatever standards are required to assure desired levels of sport and commercial fishery stocks. With the great volumes of water with which we are dealing, if water quality is ever allowed to fall below these conditions, the cost of reclamation programs could well be outside the realm of economic feasibility.

MANAGEMENT-ORIENTED REQUIREMENTS

In order to obtain maximum benefits from management of fishery resources of Lake Superior, an integration of biological and economic objectives will be required. In the management of a fishery, the role of the biologist is to provide information on biological potential, while the task of the economist is to indicate within the biological potential, the level of fishing effort that will produce the maximum economic return. It is the role of the resource administrator to blend these considerations into a rational management policy for the public benefit. Efficient management necessitates a combined effort. While this future management must be considered within the context of the overall Great Lakes fishery, the particular characteristics of the Lake Superior situation require special adaptations of overall Great Lakes management policies and objectives.

In analyzing the management requirements it should be kept in mind that Lake Superior waters cannot be classified as highly productive. Historically, the annual commercial production in pounds per acre has been around 0.80. Also, in dealing with a resource as large and diverse as this, only indirect methods of management have been employed in the past. It is only within recent years that more direct methods have proven feasible, notably control of the sea lamprey and successful introduction of some exotics.

The sea lamprey control program must be considered as the key element in the fishery management programs. For unless the lamprey is controlled, the lake will be unable to support useable populations of high-value sport and commercial species. Considerations in this section are based upon the assumption that the sea lamprey control program will be carried out at an effective level.

Provision for the future growth and development of the sport and commercial fishery requires a management perspective based on the entire lake, complemented by a system of flexible regulations that can adapt to fluctuating fish populations, changing economic conditions, and new technological developments. With the authority given to the States under recent entry laws, management of this sort becomes practical and possible. If the lake is to be managed for its optimum return to the fisheries, then this type of management must come about. For over the long run a flexible and equitable system of limited entry managed on an interstate basis will greatly improve the efficiency and viability of the commercial fishing industry, while safeguarding the supply of fish stocks.

From the standpoint of ideal management of the total fishery resource in Lake Superior, an international approach to planning, regulatory programs, and ecological problems would be desirable. However, there are major institutional problems in realistically implementing this approach. Nevertheless, it is important to maintain this perspective and to draw it to the attention of the appropriate international bodies where they exist. Where adequate international institutional arrangements do not exist, their formation should be considered.

In addition to development of a more flexible and effective institutional framework, there is need for such basic management operations as continuous monitoring of biological and environmental parameters.

Fish stocks and environmental conditions in most of the Great Lakes waters have undergone extremely rapid changes within the past several decades. Development of appropriate fisheries management programs must be based on an awareness of these changes and the timely recognition of significant trends.

Biological programs should be geared to providing the necessary data for indirect management. Ability to predict species abundance and distribution would permit advance adjustment by the fishery and management agencies. This need is of utmost importance under conditions of limited entry management. Equally important is the research and follow-up now underway on the large-scale stocking of anadromous species. Results of these studies will allow more effective management decisions and necessary adjustments in the program.

Against these overall management considerations, a biological research program oriented specifically to the conditions of Lake Superior should be given priority, to achieve the following long-range objectives:

1. To understand those aspects of the life histories and population dynamics important to the management and judicious exploitation of Lake Superior fisheries. Of primary importance are natural and fishing mortalities, estimates of yield, growth, year-class strengths, relative abundance, species inter-relations, movements and migrations, areal and depth distribution, and reproduction.
2. To obtain information on the survival and habits of stocked lake trout, as well as introduced stocks such as the coho and chinook salmon.
3. To obtain information on the environment and its relationship to fish populations. Water quality studies, including trends, deserve high priority.
4. To develop methods of obtaining necessary data on important aspects of life history.

The systematic collection and analysis of information on the abundance and biological characteristics of fish stocks are vital to the objectives outlined above. Continuous sampling is necessary to keep abreast of the constantly changing structure of fish stocks, particularly the lightly-fished species. Representative samples and accompanying relevant information should be collected, with due regard to the adequacy of information provided by the commercial and sport fisheries.

Information on the relative abundance, growth, and survival of the young of principal species, obtained by systematic sampling, will make it possible to forecast their abundance when they eventually enter the fishery. This knowledge would be of practical value to the industry in preparing markets and readying appropriate fishing gear. It would also be useful to agencies responsible for managing or carrying out investigations of the fishery.

ENVIRONMENTAL RESEARCH REQUIREMENTS

In order to obtain maximum benefits from an environmental research program and to assure continuity in data collection, there must be adequate coordination and exchange of information. Because fishery agencies have a broad responsibility to maintain harvestable surpluses, while contributing to man's understanding and control of aquatic living resources and their environment, it seems logical that these agencies should also have a major role in coordinating and conducting research related to long-term water quality changes. Without proposing any specific institutional arrangements, this function could logically be exercised through such established mechanisms as the Great Lakes Fishery Commission, which could help to promote an ecosystem approach.

Areas in particular need of additional research and investigation include:

1. Monitoring Environmental Conditions and Changes.--Continuous measurement and evaluation of basic environmental features are needed. This will provide the background of information required to interpret and predict fluctuations and trends in fish distribution and abundance. The limited amount of such work done in the past on Lake Superior underscores the need for acceleration. Such studies should extend to the tributaries of Lake Superior, to sources of domestic and industrial pollution, and to those physical and

chemical processes within the lake which concentrate, add, or remove material. Information from current research relevant to fishery problems could be obtained and evaluated to permit the correlation of fish population dynamics with the increased knowledge of environmental change. Presently, sampling and investigatory data are inadequate to do this in a meaningful way in Lake Superior.

2. Pesticide Research.--Although BCF investigations have shown levels of DDT and dieldrin in Lake Superior fish to be relatively low compared with the other Great Lakes, these levels are significant. The tendency for high quality fish, especially salmonids, to take these substances up and concentrate them in their flesh, plus the tendency for the concentrations to increase as the fish grow larger, makes this group particularly vulnerable. Since the future of a balanced sport and commercial fishery in Lake Superior and its tributaries will be geared to a resource base of high quality fish, the importance of accelerated work in this area is obvious.

3. Effects of Specific Pollutants and Water Quality Changes on Fish and Aquatic Life.--From the standpoint of their life history, very little is known of the specific effects of pollutants and water quality changes on desirable fish and aquatic life. The lack of this information makes it very difficult to apply precise standards. As a

result of the 1965 Water Quality Act, Michigan, Wisconsin and Minnesota have developed broad water quality standards to protect the fish and wildlife resources of Lake Superior. These standards must be considered interim in nature since much has yet to be learned about aquatic life requirements. Additional research may demonstrate the need for redefinition and refinement of the standards to meet fish and wildlife requirements. Until careful research demonstrates beyond a reasonable doubt that degradation of Lake Superior's high water quality downward to the level of the standards will not result in harmful effects on fish and wildlife resources, it is the position of the U. S. Fish and Wildlife Service that the goal of pollution abatement in Lake Superior should be retention of the existing overall high quality of its waters.

CONCLUSIONS

On the basis of a framework-type analysis appropriate for this report, the following conclusions are drawn concerning the status of Lake Superior's fish and wildlife resources.

FISHERY RESOURCE BASE

1. Lake Superior has been historically dominated by salmonid fishes. The three principal species in the commercial catch have been lake trout, whitefish and lake herring. Lake trout, smelt, coho salmon, rainbow trout, brook trout, whitefish and perch are important sport fish species.
2. Though there have been some changes in the fishery stocks throughout the period of record, the major changes have occurred during the last two decades. Lamprey predation and heavy fishing pressures caused the lake trout population to collapse during the 1950's.
3. The lake herring population began showing evidence of change in the mid-1950's and underwent a steady decline during this decade.
4. Changes in the chub populations have resulted in the bloater chub becoming the principal chub species in the lake.
5. The introduced smelt is probably the most common inshore species in the lake today. It is extensively harvested by sport and commercial fishermen. The alewife has not increased in Lake Superior to the extent that it has in the other Great Lakes.

6. Coho salmon were introduced relatively recently. Their importance has not been fully determined in Lake Superior, but sport fishermen are giving them considerable attention.

The Commercial Fishing Industry

1. The peak decade for commercial production in Lake Superior was during the 1940's. The fishery has undergone a steady decline in both total production and value since the early 1950's, primarily due to the decline of the high value species.
2. The number of commercial fishermen has also declined during the same period. There were 475 fishermen operating on Lake Superior in 1966, as compared to 834 a decade earlier. During this period, the percentage of full-time fishermen declined, with most now fishing only part-time or casually. Most commercial fishing operations are marginal and there are few fishermen with gross sales adequate to cover all costs.
3. The gill net still accounts for 90 percent of the catch, with little indication of fisherman interest or financial capability of investing in more modern gear such as trawls.
4. The fish processing industry has also declined during the same period. In 1964 there were only 10 "first handlers" compared to 21 in 1959.
5. The future of the lake's fisheries (both sport and commercial) will depend upon establishment of a balanced

ecosystem and restoration of high value species such as lake trout and whitefish, along with increased utilization of currently underutilized species.

Sport Fishing

1. Sport fishing interest has increased significantly in Lake Superior and its tributaries during recent years. Lake trout, rainbow trout, brook trout or "coasters", coho salmon, perch and smelt constitute the more important species in the sport catch. Whitefish are taken, but less frequently. Winter fishermen concentrate considerable effort on lake trout.
2. Charter boat fishing is attracting considerable recent attention, with lake trout and coho salmon receiving the most attention. The Apostle Islands area is especially popular.
3. Smelt runs attract thousands of fishermen each spring, with fishermen concentrating at or near the mouth of numerous tributary streams to do their smelt dipping.
4. In 1965, some 300,000 sport fishermen spent an estimated 5,520,000 fisherman days in Lake Superior Basin. This figure is expected to increase to 8,300,000 by 1980, and to 20,000,000 by 2020.

WILDLIFE

1. Lake Superior Basin provides a wide variety of hunting, with deer, ruffed grouse, and waterfowl providing most of

the opportunity. Moose have again become locally common in Minnesota and may provide limited hunting in the future. Beaver are numerous and trapping of mink and beaver provides considerable recreation and some income. The timber wolf is an important wildlife species, particularly in Minnesota portions of the basin.

2. In 1965, some 200,000 hunters expended an estimated 2,740,000 hunter days in the basin. This figure is expected to increase to 4,000,000 hunter days by 1980, and 5,500,000 by 2020.
3. Loss of habitat through forest succession or other causes, together with injudicious use of insecticides, and other activities of man, is beginning to encroach upon wildlife in some parts of the basin.
4. Water pollution has had relatively little effect upon wildlife in most parts of the basin.

HABITAT BASE AND ENVIRONMENTAL CONDITIONS

1. Lake Superior is the only one of the Great Lakes where water quality (of the open waters) is still essentially in its original condition. Concentrations of dissolved solids are low, with very little change occurring during the period of record (1880 to the present).
2. This is an oligotrophic lake and the least productive of the Great Lakes. It has an average yield of 0.8 pounds of commercial fish harvest per acre per year.

3. The human population density is low throughout most of the Lake Superior Basin, especially in comparison with Lakes Michigan, Erie and Ontario. Severe pollution enters the lake from relatively few sources.
4. The open waters of Lake Superior represent a huge reservoir of high quality waters. Discharge from this natural reservoir into the rest of the Great Lakes system exerts the principal beneficial effect in the improvement of water quality levels in the lower lakes, particularly Lake Huron.
5. The inshore waters of Lake Superior as a whole do not as yet exhibit widespread indications of severe water quality deterioration. However, there are important localized exceptions, including the taconite problem at Silver Bay, Minnesota; the lower St. Louis River, also in Minnesota; and the paper mill wastes at Nipigon Bay, Ontario. Municipal and industrial mill wastes from the comparatively few population concentration points in the basin also contribute to the total.
6. Overall water quality changes throughout the Lake Superior ecosystem are relatively minor to date. Although they have not proceeded to a point resulting in demonstrable adverse effects on fish and wildlife resources, these changes should be viewed seriously. They are indicators that steps should be taken without delay to slow down, and eventually halt, inputs of pollution.

7. From the standpoint of fish and aquatic life, these scattered signs of trouble in the inshore waters should be read for what they are -- symptoms and warnings that decisions should be made now as to what future water quality trends are to be encouraged. Any needed action should be taken soon.
8. Retention of Lake Superior's unusually high quality environment is a much more practical approach than attempts to restore these waters after they are contaminated.
9. While the concentration of pesticides in fish is comparatively low, these concentrations have accumulated over a relatively few years and projections on this basis are a cause for concern. The capacity of salmonid fishes to accumulate these substances, particularly as they attain larger sizes, poses a serious problem for fishery managers.
10. As a result of the 1965 Water Quality Act, Michigan, Wisconsin and Minnesota have developed water quality standards to protect and upgrade waters of their states. With the exception of the temperature standards proposed by Michigan, the Secretary of the Interior has approved all of the water quality standards proposed by the three States. Most of the open water of Lake Superior currently exhibit higher water quality than called for by the statewide standards.

11. Much remains to be learned about water quality criteria and their relationships to aquatic life. Additional research may demonstrate the need for re-definition and refinement of standards to meet fish and wildlife requirements. In the meantime, on a statewide basis, the standards are considered the minimum necessary to maintain various aspects of quality habitat. In view of the rapid changes occurring in the Great Lakes ecosystem, every effort should be made to maintain existing quality in those areas where it currently exceeds the minimum standards. This should include close monitoring so that any changes in water quality will be promptly detected.

12. Because of their inherent sensitivity to subtle, long-range environmental changes, fish and aquatic organisms make excellent indicators of such changes, thus enabling water quality problems to be recognized and corrective action taken before the problems become critical. Heretofore, this has not been recognized sufficiently. A change of emphasis is needed, with acceleration of research and monitoring programs involving fish and other aquatic organisms in an indicator role in water quality studies.

13. Because of the involvement of fish, wildlife and aquatic organisms in long-term changes in water quality

and the special responsibilities of State and Federal fishery agencies in this general area, research on long-range environmental changes should be conducted by these agencies. It should be coordinated through established institutions such as the Great Lakes Fishery Commission, with the help and cooperation of private and educational groups.

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